NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

THESIS

FULL-DUPLEX UNDERWATER NETWORKING USING CDMA

by

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March 2004

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REPORT DOCUMENTATION PAGE	*Form Approved OMB No. 0704-0188*

1. AGENCY USE ONLY *(Leave blank)*	**2. REPORT DATE** March 2004	**3. REPORT TYPE AND DATES COVERED** Master's Thesis

4. TITLE AND SUBTITLE: Full-Duplex Underwater Networking Using CDMA	**5. FUNDING NUMBERS**
6. AUTHOR(S) Kurtulus BEKTAS	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Postgraduate School, Monterey, CA 93943-5000	**8. PERFORMING ORGANIZATION REPORT NUMBER**
9. SPONSORING /MONITORING AGENCY NAME(S) AND ADDRESS(ES) N/A	**10. SPONSORING/MONITORING AGENCY REPORT NUMBER**

11. SUPPLEMENTARY NOTES The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.

12a. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release; distribution is unlimited	**12b. DISTRIBUTION CODE**

13. ABSTRACT (maximum 200 words)

Establishing a full-duplex underwater network, researching and applying a CDMA protocol to this network, providing a recommendation for a full-duplex underwater network and providing recommendations for using CDMA to increase the efficiency of this network are the general scope of this thesis.

A connection that allows traffic in both directions simultaneously underwater is the example of full-duplex communication. Compared to a half duplex configuration, the full duplex network underwater may provide a better networking environment. Currently, most Underwater Acoustic Networks (UANs) still utilize half-duplex network communication. CDMA is the third kind of channel partitioning protocol. Most of the wireless communication devices utilize different kinds of CDMA protocol as a reliable and faster communication. The research conducted in establishing a full-duplex UAN using CDMA may provide reliable and faster communication compared to half-duplex.

14. SUBJECT TERMS Full-Duplex, Half-Duplex, CDMA, Spread Spectrum, Acoustic Modem, Underwater Acoustic Networks, Temperature, Salinity, Pressure, Noise, Multipath.	**15. NUMBER OF PAGES** 173
	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	**18. SECURITY CLASSIFICATION OF THIS PAGE**	**19. SECURITY CLASSIFICATION OF ABSTRACT**	**20. LIMITATION OF ABSTRACT**
Unclassified	Unclassified	Unclassified	UL

NSN 7540-01-280-5500 Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18

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FULL DUPLEX UNDERWATER NETWORKING USING CDMA

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Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN COMPUTER SCIENCE

from the

NAVAL POSTGRADUATE SCHOOL
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ACKNOWLEDGMENTS

I would like to thank to my supportive mother Urkus Bektas and father Munup Bektas.

I am also thankful to have a wonderful girlfriend Traci Ketchum who supported me with love and patience throughout this thesis.

Finally I would like to thank Professor Geoffrey Xie, John Gibson and Chief Engineer of Desert Star, Andy Goldstein for their support.

Everything was for croissant and star.

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I. INTRODUCTION

The history of underwater acoustics, networking and wireless technology has taken many different forms over the years. During the 20th century, information gathering, processing, and distribution became the dominating technology. [1] As we move into the 21^{st} century, networking and wireless technologies are emerging as the dominate technologies.

The primary focus of this thesis is testing the feasibility of a full-duplex Underwater Acoustic Network (UAN) using four Desert Star modems and developing a new protocol based on Code Division Multiple Access (CDMA) using the Desert Star modem application.

Many factors have slowed the development of UANs. The most important reason is the challenge of achieving a reliable high-capacity wireless network. The underwater environment dramatically effects signal propagation. The propagation speed of acoustic signals is several magnitudes slower than that of airborne radio signals. The water temperature, salinity, and pressure dictates how fast sound will travel, therefore making high speed data transfer rates difficult to achieve. [2] Moreover, absorption, scattering, refraction and distance between nodes are a larger concern in underwater networking because of the data loss and errors associated with each of these anomalies.

All existing acoustic modems operate in a half-duplex mode. Half-duplex communication exacerbates the negative effects of propagation delay on data transfer latency by requiring the exchange of several control packets to establish media access. Establishing full duplex connections between each pair of nodes assures access to the media without the exchange of access requests prior to each traffic exchange session. Therefore, using full-duplex connection should reduce the negative effect of large propagation delays on channel use [3]. In fact, full-duplex communication has been successfully implemented under a similar context. Satellite communication is one example of air-based full-duplex implementation. In satellite communication, the uplink and the downlink channels use different frequencies to realize full-duplex communication in order to mitigate the large propagation delays caused by the long propagation distances.

An NPS graduate student has recently evaluated the feasibility of configuring full-duplex channels on commercial acoustic modems [4]. The results are not encouraging, which indicates that the existing acoustic modem software is not amiable to full-duplex communication. This thesis takes the next step and investigates possible ways of enhancing the acoustic modem software to support full-duplex communication.

A. MULTIPLE ACCESS TECHNIQUES

The implementation of full-duplex communication must be built upon a multiple access technique. Multiple access is a mechanism whereby many subscribers or local stations can share the same communication medium at the same time or nearly so, despite the fact that their individual transmission may originate from widely different locations [5]. There are four basic classes of multiple access techniques: Frequency-Division Multiple Access (FDMA), Time Division Multiple Access (TDMA), Code Division Multiple Access (CDMA), and Space Division Multiple Access (SDMA).

FDMA assigns non-overlapping frequency ranges to different signals or users on medium. By doing this, each signal can be transmitted simultaneously as long as the frequencies are different. Synchronous TDMA assigns time slots to a user on a given medium. It then accepts input from each slot in a round-robin fashion based on the time allotted to each slot. This protocol allows the devices to send data in a never ending pattern. But, because the protocol is constantly switching between slots, even if there is no data, there is a lot of bandwidth waste. Because of this waste, bandwidth asynchronous TDMA (A-TDMA) was developed to improve synchronous TDMA. A-TDMA only transmits data from an active workstation; therefore, no space is wasted on the multiplexed stream. The input data is then sent to a statistical multiplexer, which creates a frame containing the data to be transmitted. This process allows a higher use of the network by ensuring that each channel is loaded to its peak capacity. While A-TDMA would be the easiest protocol to implement, it will not be used because of the difficulties in synchronizing nodes because of propagation delays. With CDMA, an advanced coding technique allows multiple devices to transmit on the same frequency at the same time. In SDMA, resource allocation is achieved by exploiting the spatial separation of the individual users. In particular, multibeam antennas are used to separate radio signals by pointing them along different directions.

B. MAJOR CONTRIBUTIONS

With the drive to implement network centric warfare in all environments, efficient and reliable underwater acoustic communication is important to the military. The research conducted in establishing a full-duplex UAN using FDMA or CDMA will significantly contribute to understanding underwater networking and advance the Naval Postgraduate School to the forefront of Underwater Acoustic Network technology. This research encompasses the benefits of full-duplex underwater networking and full-duplex underwater networking using CDMA. These solutions will increase the efficiency and reliability of underwater data transfer, and in turn they could be used for further research or as a stepping stone toward improved monitoring of oceanographic anomalies and littoral waters, as well as command and control of littoral forces. It is proven that CDMA is very effective in radio frequency (RF) wireless networks. Therefore, it is widely used in the air for wireless communication. If the same robust performance can be achieved in the underwater acoustic channel, then the future design and development of underwater networks can integrate many of the techniques that have proven so successful in RF wireless networks.

C. ORGANIZATIONS

This thesis is organized with the following chapters:

- Chapter II discusses the background of acoustic communication and spread spectrum technology. NPS full-duplex effort will also be discussed in this chapter.
- Chapter III discusses the understanding the system hardware, software and the operation of the modems. Full-duplex UAN system design will also be discussed in this chapter

- Chapter IV discusses Code Division Multiple Access (CDMA) techniques and the Desert Star code modifications regarding these techniques. Spreading Sequence with Walsh Code will also be discussed in this chapter.
- Chapter V discusses the CDMA modifications, tests procedures and results, and the conclusions of these tests.
- Chapter VI provides conclusions and recommendations for future Naval Postgraduate School efforts.

II BACKGROUND

This chapter discusses Acoustic Communication Basics and Spread Spectrum. Prior NPS work on full-duplex acoustic communication is also discussed.

There are some challenges for underwater acoustic communication. However Spread Spectrum CDMA techniques have better solutions and they provide several users to communicate independently by using the same higher bandwidth.

A. ACOUSTIC COMMUNICATION

Underwater communications use acoustic pressure waves to propagate signals through the water, unlike radio frequency (RF) communications, which use electromagnetic waves. The characteristics of the underwater acoustic channel and some of the difficulties it imposes on communications signals will be discussed in this section.

Three major challenges are inherent with underwater acoustic signals. The first challenge is multipath fading that occurs as a result of destructive interference. Reflections off the sea bottom and the sea surface, as well as scattering from non homogeneities in the water column, result in multiple receipts of the same signal at the receiver. These multiple arrivals superimpose on each other and deform the signal in amplitude and phase. Similarly, the motion of the source, the receiver and the medium itself result in Doppler shifts and Doppler spreading, which further distort the signal. Figure 1 illustrates some of these time-varying processes. The second challenge is bandwidth limitation. High frequencies are strongly attenuated in the ocean, which result in relatively small transmission bandwidths and relatively low data rates compared to those achievable in RF communications. The last challenge is the ocean noise that is non-Gaussian and results from many systems including biologics, weather, surface wave action, shipping, and industrial noise near the coastline. The following sections explain these challenges in detail.

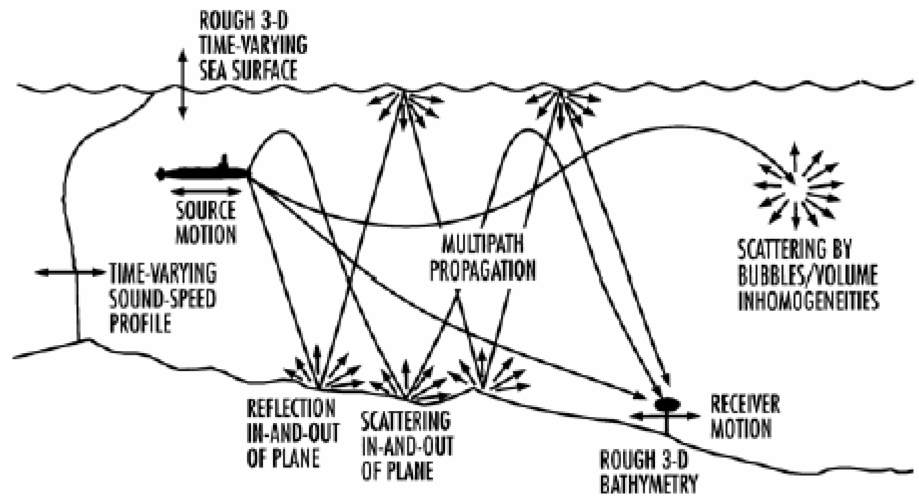


Figure 1. Some of the Major Processes Affecting Fading in the Underwater Acoustic Communication Channels [From Ref. 6]

1. Multipath Fading

The time spreading of the signal and the time-variant nature of the channel are causes of multipath fading in digital communication channels.

a. Time Spreading

Time spreading is the distortion of the signal period by extending the time over which the signal element arrives, causing inter-symbol interference unless a larger guard space is included between symbols, thus reducing the symbol rate. When multiple versions of the transmitted signal arrive at the receiver, time spreading occurs. Time spreading is also referred to as time dispersion or multipath propagation. In the underwater acoustic channel these multipath arrivals result from reflections off the sea surface and sea bottom, refraction and scattering within the ocean volume. The reflection and refraction pattern of the sound waves is directly related to the geometry of the channel and the sound velocity profile. Figure 2 shows one example of sound-wave propagation in the underwater channel, where z is the water depth, c is the sound speed in water and r is the range.

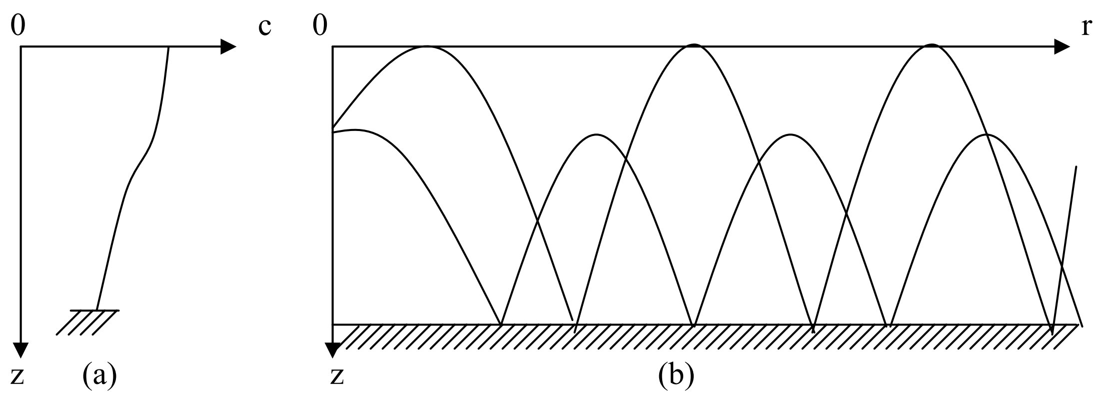


Figure 2. An example of sound propagation in a shallow water where (a) is the sound speed profile and (b) is a ray diagram representing two sound rays propagation from the source [From Ref. 7]

The random amplitude and phase of the multiple arrivals cause fluctuations in the received signal strength. One way of characterizing the effect of multipath in a channel is the channel impulse response, $h(\tau)$, as a function of the excess delay, τ, for a transmitted impulse. However, in communication channels, it is more common to refer to the multipath intensity profile (MIP), which is a measure of the average received power, $S(\tau)$. The excess delay is the time delay that occurs after the first arrival of the signal. Figure 3 shows an example of an MIP.

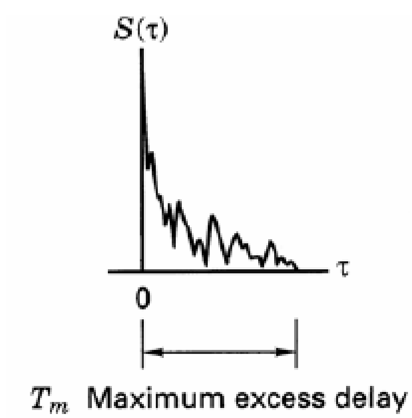


Figure 3. An Example of a Multipath-Intensity Profile [From Ref. 8]

The maximum excess delay, T_m, is the period of time during which the MIP is essentially non-zero. In the frequency domain, the time-spread signal can be classified by its coherence bandwidth, B_{COH}. The B_{COH} is a statistical measure of the bandwidth over which the channel passes all frequency components with equal gain and equal phase. This also means that the frequency components are well correlated and that the channel's frequency-transfer function is essentially flat. T_m and B_{COH} are related by $B_{COH} \approx 1/T_m$. However, this is not the best way to classify a channel because the $S(\tau)$ may vary significantly for channels with the same T_m. Therefore, a more useful parameter is the root-means-squared delay spread, σ_τ, given by:

$$\sigma_\tau = \sqrt{\overline{\tau^2} - \overline{\tau}^2} \, .$$

Equation 1. Squared Delay Spread

where $\overline{\tau}$ is the mean excess delay [9]. If B_{COH} is then defined as the frequency interval over which the channel's complex frequency transfer function has a correlation of at least 0.9, then B_{COH} becomes [9]:

$$B_{COH} \approx \frac{1}{50\sigma_\tau} \, .$$

Equation 2. B_{COH} Defined as the Frequency Interval

A time-dispersive channel can be classified as *frequency selective* or *frequency non-selective*. In a *frequency selective* channel, the signal bandwidth, W_s, is larger than the coherence bandwidth ($B_{COH} < W_s$) and, therefore, significant distortion occurs since the spectral components of the signal are affected differently. In the time domain, this means that the symbol duration, T_s, is much smaller than the maximum excess delay ($T_s \ll T_m$). Thus, successive data pulses will interfere with each other. This is called *channel-induced inter-symbol interference* (ISI).

In *a frequency non-selective* channel, the transmitted signal's bandwidth, W_s, is smaller than B_{COH}, (i.e., $B_{COH} > W_s$). Therefore, the channel affects all spectral components of the signal equally. In the time domain, this means that all the symbol multipath components arrive within the symbol duration, $T_m<T_s$. Consequently, there is no channel induced ISI. In a shallow water underwater communication channel, T_m can vary greatly but values on the order of ten milliseconds are not untypical [10].

b. Doppler Spreading

The coherence bandwidth and delay spread characterize the time dispersive properties of the channel but do not address its time-varying nature. If there was no motion in both the transmitter and receiver, and the channel was stationary, the channel would appear time invariant. The time variance is a result of the motion within the channel, specifically movement of the source, the receiver, or the channel itself. In the water channel, the motion of the water, either due to currents, tides, or other influences, results in movement of the channel. The variance, then, results in propagation paths that are different from moment to moment; therefore, the channel-impulse response varies over time.

The parameters used to describe the channel's time-varying nature are its Doppler spread and coherence time. Doppler spread, B_D, is a measure of the spectral broadening of the signal caused by the channel's rate of change and is the range of frequencies over which the Doppler spectrum is essentially non-zero. The coherence time, T_{COH}, of the channel is a statistical measure of the time duration during which the channel impulse response is essentially time-invariant. The mathematical relation between the Doppler spread and coherence time is described as $T_{COH} \approx 1/B_D$. Source receiver motion and sea surface roughness are the dominant mechanisms resulting in Doppler spread [11]. If source and receiver are fixed, then the Doppler spread due to wind driven weather effects at the sea surface can be expressed as:

$$B_D = 2 f_w \left[1 + \frac{4\pi f_0 \cos\theta_0}{c} \right] h_w .$$

Equation 3. Doppler Spread due to Wind-driven Weather Effects at the Sea Surface where f_w is the wave frequency given by $f_w = 2/w$, w being the wind speed in m/s, f_0 is the carrier frequency, θ_0 is the angle of incidence and h_w is the wave height of the surface waves given by $h_w=0.005w^{3/2}$ [11]. Again, B_D can vary greatly, but without a moving source or receiver and in relatively low sea states, Doppler spreads of less than 10 Hz are not untypical.

The two types of Doppler spread channel are *fast-fading channel* and *slow-fading channel*. In a fast-fading channel, the channel's characteristics (i.e., impulse response) change faster than the symbol duration, $T_{COH}<T_s$. In a slow-fading channel, the symbol duration is less than the coherence time $T_{COH}>T_s$; therefore, the channel is essentially time invariant over the duration of the symbol. A slow-fading channel is more desirable from a detection perspective, so symbol rates can be increased to meet this requirement, as long as there is a way to compensate for the channel-induced ISI that may result.

c. Doubly Spread Channels

The shallow water communications channel that undergoes both time and Doppler spread is called a doubly spread channel. The product, B_DT_M, is called the spread factor. If $B_DT_M<1$, then the channel is said to be under spread and if $B_DT_M>1$ it is called overspread. In under spread channels, the channel impulse response can be determined reliably and used to aid the receiver in demodulating the signal. In an overspread channel, this is not possible and high data error rates occur. A spread of less than 10^{-3} is needed in the underwater acoustic channel for coherent or differentially coherent detection [12].

2. Band-Limitation

The transmission loss (i.e., large-scale fading) severely restricts the bandwidth of the underwater acoustic communication channel. The two main factors affecting transmission loss are attenuation and spreading [2].

Attenuation is the absorption and scattering of the sound wave while it propagates. Absorption is a more significant challenge than the other two and involves conversion of the acoustic energy into heat. Scattering occurs from the ocean bottom, the inhomogeneous volume of the ocean, and the surface of the sea. Scattering increases the attenuation of the signal due to poor directionality. However in practice, distinguishing between the two effects is impossible. Therefore, they are usually combined into one term. Figure 4 shows the strong dependence of attenuation on frequency. The dependence is divided into four regions.

Transmission loss due to spreading is proportional to $1/R$ for cylindrical spreading and $1/R^2$ for spherical spreading, where R is the range between the source and receiver. Spreading is a geometric effect caused when the intensity of the sound field weakens while the field expands over a larger volume. In shallow water channels, spreading behavior is usually between cylindrical and spherical, and is here assumed to be $1/R^{3/2}$.

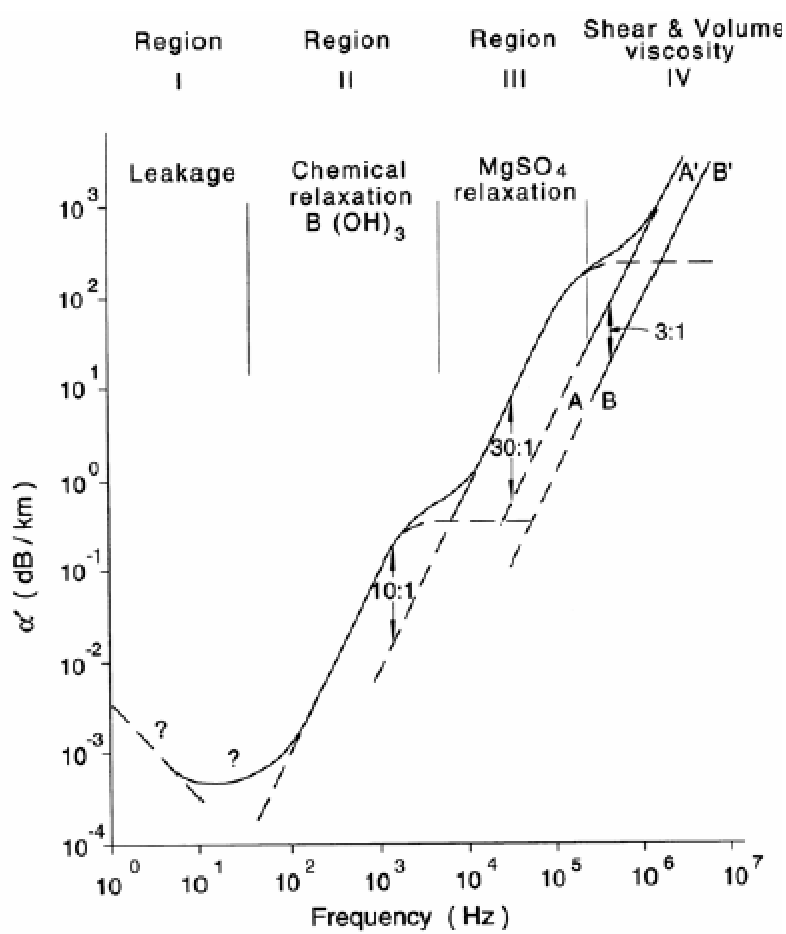


Figure 4. Attenuation Coefficient for Acoustic Energy in Seawater [From Ref. 13]

The effects of Region I are not well understood. The two regions, Regions II and III are dominated by the chemical relaxation of two constituents in seawater. The viscosity of the seawater dominates Region IV.

A mathematical expression for the attenuation coefficient is available as follows:

$$\alpha \approx 3.3\times10^{-3} + \frac{0.11f^2}{1+f^2} + \frac{44f^2}{4{,}100+f^2} + 3.0\times10^{-4} f^2 .$$

Equation 4. Attenuation Coefficient

where α is in dB/km [13] and f is the frequency in kHz and the four terms are sequentially associated with the four regions in Figure 4. With both spreading and absorption, the overall transmission loss (TL) expression is given by:

$$TL = 15\log R + \alpha R \times 10^{-3} .$$

Equation 5. Transmission Loss

where TL is in decibels referenced to 1 micro-Pascal (dB re 1µPa) and R is in km [2]. Decibels are used to compare values of like quantities, usually power and intensity, on a numerical scale. For example, an intensity ratio of 100 translates to a level difference of 20 decibels. To be meaningful, a decibel needs a referenced point. For example, in water we use a standard reference sound pressure of 1 micro-Pascal, and in air we use a higher standard of reference of 20 micro-Pascals.

3. Non-Gaussian Challenge

In the underwater communication channel, noise is non-Gaussian. Noise levels vary greatly over time and geographic location, and different sources dominate in different bands. Therefore, developing good statistical representations of the noise is difficult. Experimental observations [2] show that at the lower frequencies (below 10 Hz) ambient noise is dominated by ocean turbulence. Noise between 50 Hz and 500 Hz is dominated by distant shipping and depends on the geographic location. At higher frequencies, 500 Hz to 50 kHz, the roughness of the sea surface dominates the noise spectrum. Sea surface roughness is directly related to the wind speeds at the sea surface and is therefore weather dependent. The Desert Star modems work between 33 kHz and 41 kHz. Therefore, the noise from the sea surface is the greatest challenge for these modems. Lastly, at high frequencies above 50 kHz, the thermal noise, due to the motion of the molecules of the sea itself, is the dominant source of ambient noise. The ambient noise levels from different sources in the deep sea may be expressed as:

$$NL_1 = 17 - 30\log f \, .$$

Equation 6. Turbulence Noise

$$NL_2 = 40 + 20(D - 0.5) + 26\log f - 60\log(f + 0.03) \, .$$

Equation 7. Shipping Noise

$$NL_3 = 50 + 7.5w^{1/2} + 20\log f - 40\log(f + 0.4) \, .$$

Equation 8. Surface Waves

$$NL_4 = -15 + 20\log f \, .$$

Equation 9. Thermal Noise

where *NL* values are in dB re 1 µPa, *f* is the frequency in Hz, *D* is the shipping density on a scale from 0 (very light) to 1 (heavy) and *w* is the wind speed in m/s [14]. Using the above expressions, Figure 5 shows one example of the cumulative effects of these sources over a broad frequency range, for a nominal wind speed of 10 m/s (20 knots) and light shipping (*D=0.5*). In the frequency band of interest, 33 to 41 kHz, the dominant noise source is wind-induced sea surface roughness.

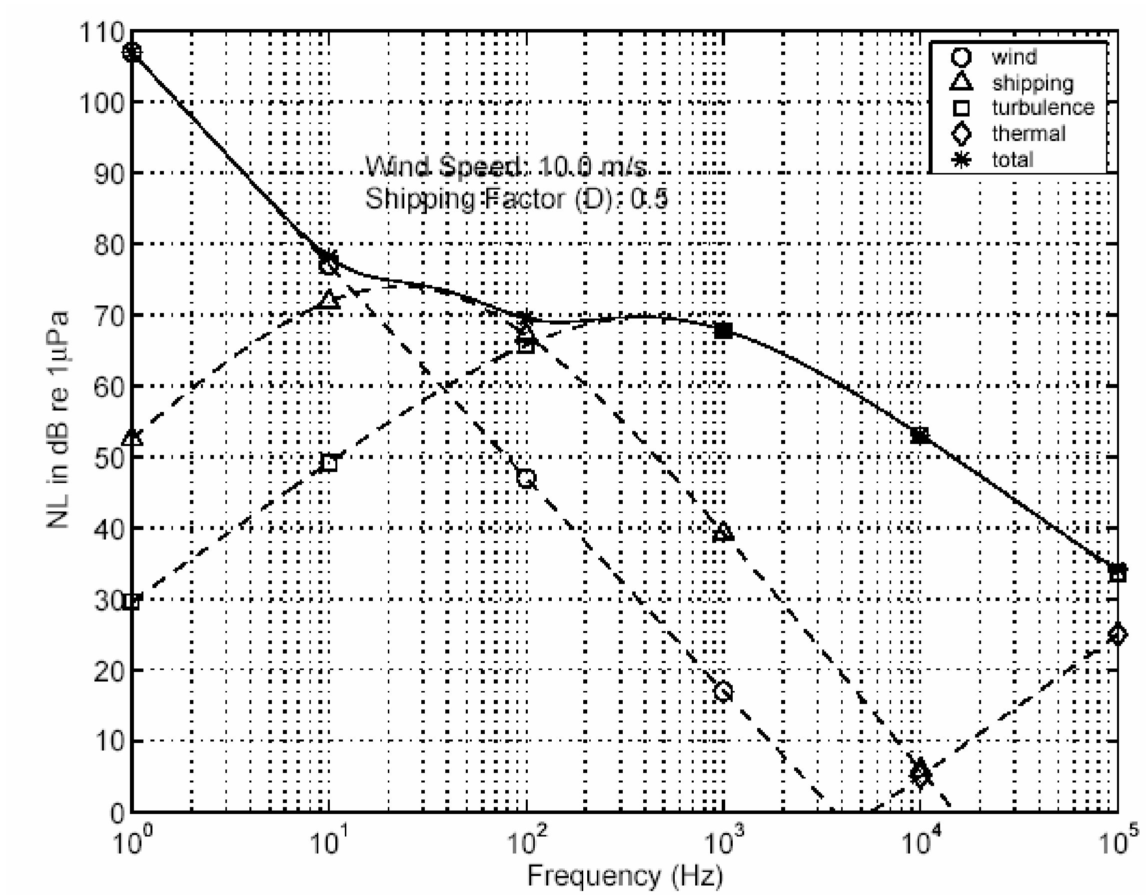


Figure 5. Deep-water Ambient Noise Spectrum Level, with Light Shipping and Nominal Sea Surface Wind Speed of 10 m/s (Sea State 4) [From Ref. 2]

When *NL* and *TL* effects are combined, the overall range and frequency dependence of the channel becomes apparent as illustrated in Figure 6.

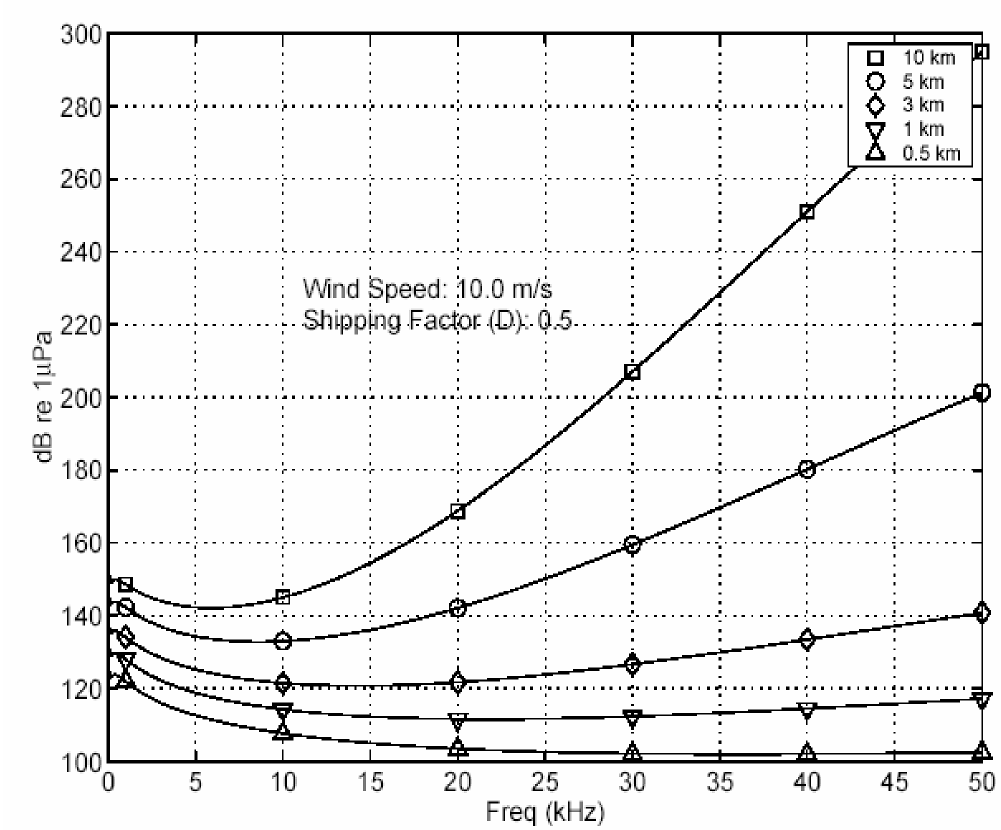


Figure 6. Frequency and Range Dependence of the Underwater Communications Channel for the Combined Effects of Noise Level (NL) and Transmission Loss (TL) [From Ref. 2]

From Figure 6, it can be concluded that the experimental RBS-1 modem's 33 to 41 kHz band is consistent with its range requirements of 1 km. However, when compared to the radio frequency communications channel, these are extremely small bandwidths. For example, the IEEE 802.11b standard for wireless networks uses DSSS and operates in the 2.4 GHz band at a data rate of between 2 and 11 megabits per second (Mbps).

Additionally there are sources of noise from biological and coastal industry in the shallow water channel. The overall noise varies significantly between the seasons, the times of day, geographic locations, shipping density, and weather and exhibits a large dynamic range. All this leads to a very noisy channel, which has characteristics that are quite difficult to represent statistically.

In this section we have seen that the underwater acoustic channel imposes significant difficulties on communication signals. The channel is severely bandwidth limited, ocean noise is non-Gaussian, and severe multipath fading occurs due to both time and Doppler spreading of the transmitted signal.

B. SPREAD SPECTRUM

Spread spectrum is a modulation technique that produces a spectrum for the transmitted signal much wider than the usual bandwidth needed to send a particular information stream. Usual bandwidth here roughly refers to the order of minimum bandwidth needed to convey a stream of information (e.g. bits) over a relatively benign channel (e.g. an additive white Gaussian noise (AWGN) corrupted channel with a high signal-to-noise ratio (SNR)). See Table 1 for an example.

	Narrowband	**Spread spectrum**
Transmitted Signal Bandwidth	5 kHz	1 MHz

Table 1. Bandwidth Comparison for a 5 kbits/sec Data Stream

Spread Spectrum is an important communication technique because it has better multipath resolution and is difficult to intercept. Spread Spectrum provides time and range, and several users can independently use the same higher bandwidth with very little interference, which is known as Code Division Multiple Access (CDMA). The most investigated application of the spread spectrum is CDMA.

There are three types of spread spectrum: Frequency-Hopping Spread Spectrum (FHSS) is the first implemented type of Spread Spectrum. Direct Sequence Spread Spectrum (DSSS) is the more recent type of Spread Spectrum, and finally the Time Hopping Spread Spectrum (THSS).

The hybrid Spread Spectrum systems include all systems that employ a combination of two or more of the above-mentioned spread-spectrum modulation techniques. Thus, the four possible hybrid systems are DS/FH, DS/TH, FH/TH, and DS/FH/TH.

A Spread Spectrum system block diagram is shown in Figure 7. Binary input data is applied to the channel encoder by the transmitter. The output of the channel encoder is an analog signal with a relatively narrow bandwidth around some center frequency. This analog signal is the input of the modulator. The analog signal is modulated according to a sequence of binary data generated by the pseudo-noise generator. After this modulation the new analog signal is transmitted through the channel. The receiver receives the analog signal and demodulates with the same sequence of binary data used by the transmitter. In other words the receiver's pseudo-noise generator generates the binary code sequence just like the binary code of the transmitter. The demodulated analog output signal is then applied to the channel decoder. The channel decoder produces the binary output data received from the transmitter.

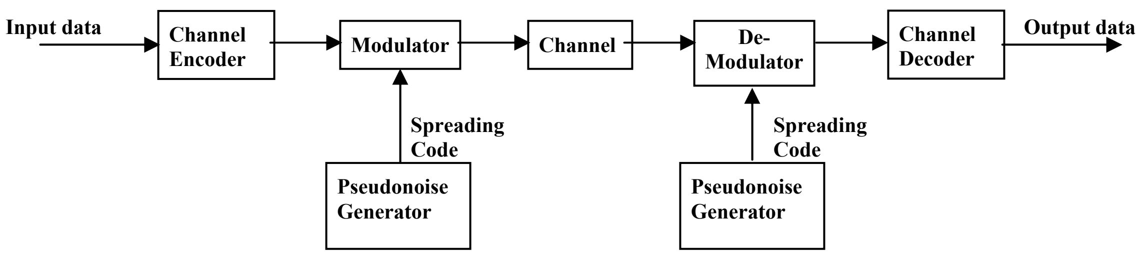


Figure 7. Spread-Spectrum System Block Diagram [From Ref. 15]

1. Direct Sequence Spread Spectrum

One non-trivial way of spreading the spectrum of the transmitted signal is to modulate the data signal by a high rate pseudo-random sequence of phase-modulated pulses before mixing the signal up to the carrier frequency for transmission. This spreading method is called Direct Sequence Spread Spectrum (DSSS). A common modulation technique for DSSS is Binary Phase Shift Keying (BPSK).

The digital information can be combined with the spreading code bit stream by using an XOR operation. There are other combination operations used with DSSS. The details of DS-CDMA will be discussed in detail in Chapter IV.

2. Frequency-Hopping Spread Spectrum

Another common method to spread the transmission spectrum of a data signal is to (pseudo) randomly hop the data signal over different carrier frequencies. This spreading method is called Frequency Hopping Spread Spectrum (FHSS). FHSS is the early implementation of the spread spectrum. The hopping sequence is the key for the transmitter and receiver. Only the transmitter and receiver know the random series of frequencies used to transmit the data. A common modulation technique for FHSS is Multi-Frequency Shift Keying (MFSK). The details of FH-CDMA will also be discussed in detail in Chapter IV.

Figure 8 shows the basic idea of the FHSS. During the specific time interval a random frequency is used to generate the analog signal. As in Figure 8, first f_5 is used to transmit the data and then f_8 is used, and so on. Typically, there are 2^k carrier frequencies for 2^k channels. The height of each gray box represents the bandwidth of the input signal. The transmitter works on a specific carrier frequency at a specific time interval. This fixed interval times is 300-ms for the IEEE 802.11. During that specific time interval and that randomly chosen frequency, some number of data signals is transmitted by the transmitter. If the receiver uses the same random frequency hopping with the same time interval, it can obtain the transmitted data.

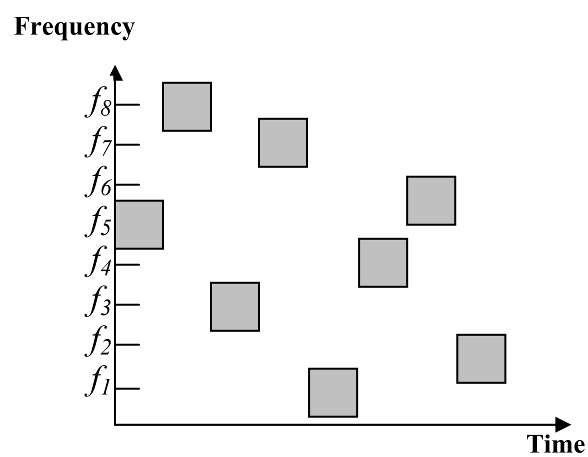


Figure 8. FHSS Basic Idea [From Ref.15]

3. Time-Hopping Spread Spectrum

In the Time-Hopping Spread Spectrum protocols, the information-bearing signal is not transmitted continuously. Instead, the signal is transmitted in short bursts and the times of the bursts are decided by the code signal. Time Hopping is similar to Pulse Modulation, with the PN sequence generator keying the code sequence to the transmitter.

The time axis is divided into frames and each frame is divided into M time slots. During each frame, the user will transmit in one of the M time slots. In which of the M time slots data is transmitted depends on the code signal assigned to the user. Since a user transmits all of its data in one, instead of M time slots, the frequency it needs for its transmission has increased by a factor M. Because of its vulnerability to interference, time hopping should be combined with Frequency Hopping or Direct Sequence Spread Spectrum. The details of TH-CDMA will be discussed in Chapter IV.

C. ACOUSTIC COMMUNICATION AND SPREAD SPECTRUM

The developments of Underwater Acoustic Networks (UAN) have been enabled by the recent improvement of acoustic modem technology. A full-duplex underwater communication effort is one part of UAN research. From the multi-user communications point of view, underwater Spread Spectrum offers better performance to establish full-duplex communication than is available with either TDMA or FDMA.

The three types of Spread Spectrum allow multiple users to communicate simultaneously in time over the same frequency band. Direct Sequence Spread Spectrum (DSSS) offers improved performance on multipath channels and simplicity, while Frequency Hopping Spread Spectrum (FHSS) offers just simplicity of implementation [16] for acoustic communication.

The receiver uses the information of the Spread Spectrum spreading code to detect the received signal that is hidden in noise or jammed by interference from other users of the network. The data to be transmitted are multiplied by a pseudo-random noise (PN) sequence, generally produced by linear feedback shift registers (e.g. Walsh Code, Hadamard Code, Gold Sequences), which is the common way for the SS-CDMA to perform this operation. The resulting signal modulates the carrier. The transmitted wave then must be demodulated by the receiver.

The primary focus of this research is to determine the implementation and performance of using Direct Sequence, Time Hopping, Frequency Hopping and Hybrid

Spread Spectrum Code CDMA as the modulation scheme to achieve full-duplex data communication with four Desert Star RBS-1 acoustic modems.

D. PRIOR NPS WORK ON FULL-DUPLEX ACOUSTIC CHANNEL

The Advanced Networking research group at the Computer Science department of the Naval Postgraduate School (NPS) has completed considerable work evaluating the AModem software system delivered with Desert Star RBS-1 acoustic modems. This work has centered around full-duplex communication using these modems.

In order to use the modems in a full-duplex configuration, the original software was modified slightly in early 2003 by Chaiporn Dechjaroen, a research assistant at the Naval Postgraduate School, to allow the user to determine what transmit and receive frequencies were to be used. These software modifications were designed to take advantage of the built-in transducer frequencies and give the user the flexibility to operate the modem in different frequency ranges.

Another project was conducted in 2003 by an NPS graduate, William R. Tate, for his MS thesis. [4] He evaluated the feasibility of a full-duplex UAN using four RBS-1 modems and experimented with a new Demand Assigned Multiple Access (DAMA) protocol to use FDMA type channels efficiently.

Although previous efforts did not succeed in demonstrating underwater full-duplex acoustic communications, the lessons learned benefited this thesis research.

III. ESTABLISHMENT OF A FULL-DUPLEX UNDERWATER NETWORK

This chapter discusses the underwater acoustic system hardware and software developed and implemented by Desert Star Systems and explains the basics of full-duplex communication. Then a new hardware system configuration solution for full-duplex communication is described.

A full duplex UAN was established using four Desert Star remote base station one (RBS-1) acoustic modems. The RBS-1 has a 33 kHz to 41 kHz omni-directional sonar transducer, with a range of 100 to 1000 meters (determined by sea conditions), and a bit rate of 15 to 150 bits per second. [17] The modems use acoustic modem software (AModem), developed by Desert Star, that allows the user to vary the transmit speed, transmit power, transmit pulse length, receive speed, receiver gain, receiver detection threshold, receiver filter number, and the checksum status. Figure 9 shows a screen capture of the AModem application launched from HyperTerminal.

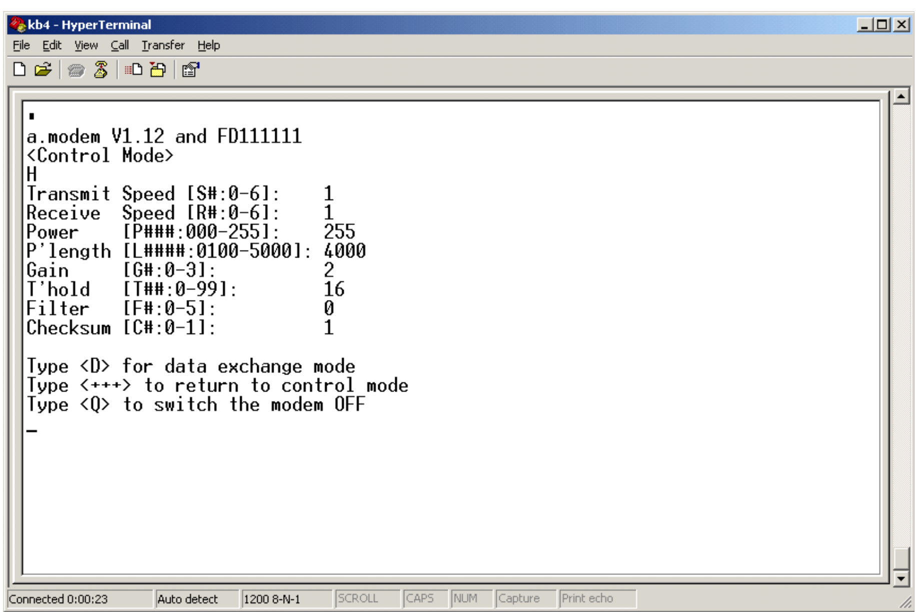


Figure 9. AModem Application Snapshot

A. UNDERWATER COMMUNICATION SYSTEM HARDWARE

Underwater acoustic communication system hardware consists of four basic components. These components are computer, modem, transducer, and special types of cables. A modem battery charger is also available to extend the modem battery life. This section discusses the characteristics of each of these components.

1. Transducer

The transducer is the antenna of the RBS-1 modem. It must be mounted so that it is not shadowed by any obstacle. The direct path between the transducers on both ends of the acoustic data link must be free of obstructions. The modem transducers, one of which is shown in Figure 10, are active in the frequency range 33 to 41 kHz. These omni-directional transducers are rated at greater than 169 dB (referenced to one micro Pascal per watt at one meter) in terms of sound pressure level. A sonar transducer cable connects the transducer to the RBS-1 modem.

Figure 10. Transducer

For the best performance, the transducer should be upright, with the cable pointing down and the mounting ring pointing up. The communication range will be reduced if the transducer is dragged into a horizontal or near horizontal position.

2. RBS-1 Modem

The RBS-1 is actually a remote baseline station that is a rugged instrument designed for use with the AquaMap long baseline survey system developed by Desert

Star. But for our full-duplex communication purpose, the RBS-1 modem is recoded for use with the AModem system. The RBS-1 modem has a battery life of approximately 130 hours per charge. One end cap is occupied by a sonar connector, while the other end cap is occupied by a multi-function serial communications connector, a power switch, and a status LED. The instruments are rated for use at depths up to 1,000 meters. A deep ocean version of the RBS-2, the RBS-2D, is rated for a depth of 7,000 meters and operates at a lower frequency range. Figure 11 shows the RBS-1 modem.

Figure 11. RBS-1 Modem

The heart of the RBS-1 modem is a 68HC11E1FN microprocessor. The AModem code is actually used to program this microprocessor.

The RBS-1 acoustic modem has two operations:

- Any data received via the serial data interface is transmitted to the water channel via the transducer
- Any data received via the transducer is transmitted to the host computer via the serial-data interface.

Figure 12 shows the data exchange between the modem, the computer, and the transducer.

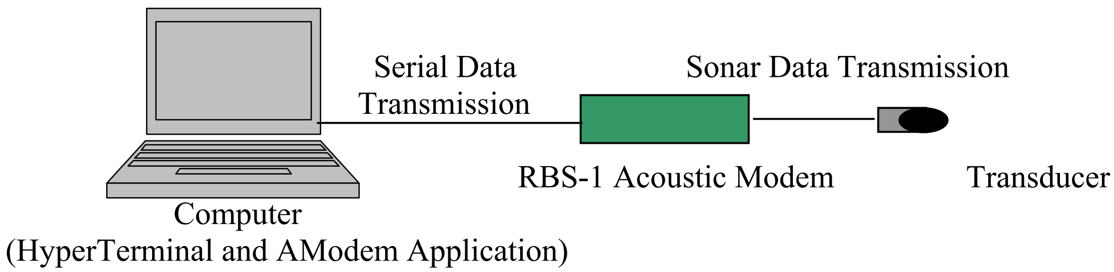


Figure 12. Example of Data Exchange

Thus, the modem has two missions. The first one is obtaining data from the user by way of the serial data interface and then reformatting and sending the data via the transducer. The second one is obtaining data from the transducer and then reformatting and sending the data to the user via the serial-data interface.

3. Modem Charger

The modem charger is designed by Desert Star. There is a power cable on one end of this charger and another cable on the other end that is compatible with the underwater cable. The RBS-1 modem Status LED indicates the current state of the charge operation. Figure 13 shows a modem charger. In order to charge the batteries in the modems, Desert Star's SmartDive application must be downloaded and selected, instead of the AModem software, via the DiveTerm application. After the SmartDive application is accessed and the modems are plugged into the chargers, the batteries are recharged in approximately four hours. If a charging problem still exists, the Set Clock option of the DiveTerm must be clicked.

Figure 13. Modem Charger

The cable shown in Figure 14 provides the connection between the modem and both the charger and the computer at the same time.

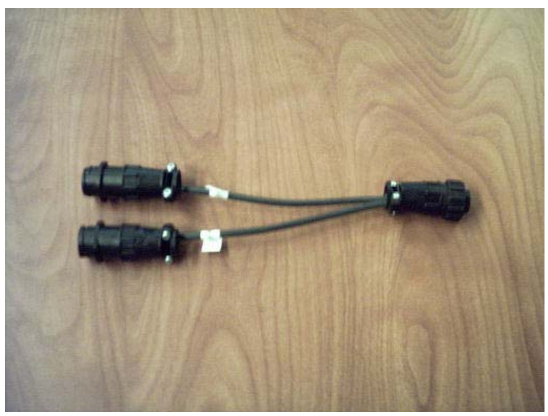


Figure 14. Computer, Charger and Modem Connection Cable

4. Connection Cables

There are three different types of cable with their connector-compatible ends to connect the computer, the RBS-1 modem and the transducer. From the computer to the RBS-1 modem, the Data Exchange cable and the Underwater Cable are used. From the modem to the transducer a Sonar Transducer cable is used. These cables are explained in the following subsections.

The Data Exchange Cable has a female RS-232 connector (DB-9) attached to interface with the host computer. If a male DB-9 serial port is not available on the computer, a serial to USB connection cable can be used to connect the Data Exchange Cable and the computer via the USB port of the computer. Using a USB connection allows one computer to control multiple modems, either through a USB hub or several USB connectors attached to the computer. Figure 15 shows the serial-to-USB connection cable.

Figure 15. Serial-to-USB Connection Cable

a. Data Exchange Cable

Figure 16 shows the data exchange cable, which is used to connect the computer and underwater cable. This cable carries the serial transmission data. One end of this cable is compatible for the underwater cable and the other end is compatible for the serial communications (COM) port of the computer, as described above.

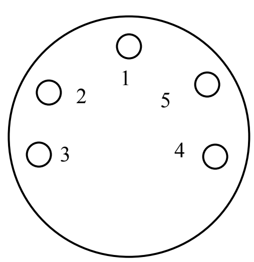
Figure 16. Data Exchange Cable

b. Underwater Cable and COM Connector

Figure 17 shows the underwater cable, which is used to connect the data exchange cable and the modem. The underwater cable is also used to charge the modems. This cable carries the serial transmission data. One end of this cable is compatible for the data exchange cable and the other end is compatible for the modem COM connector.

Figure 17. Underwater Cable

This five-pin waterproof COM connector is located at one end of the modem. The pin out of the connector is shown in Figure 18. It is a McArtney type BHMC5F, which mates to a model ILMC5M cable connector.



1: Ground

2: Receive Data (RXD)

3: Transmit Data (TXD)

4: Charger Input

5: Not Assigned

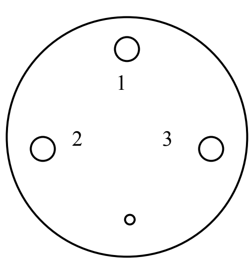
Figure 18. COM Connector Pin Out

c. *Sonar Transducer Cable and Sonar Connector*

Figure 19 shows the sonar transducer cable, which is used to connect the transducer and the RBS-1 modem. This cable carries the sonar transmission data. The sonar transducer cable has a compatible end for the transducer. The other end of this cable is compatible with the SONAR connector.

Figure 19. Sonar Transducer Cable

The connection between the sonar transducer cable and the modem is established by way of the sonar connector. This three-pin waterproof connector is located at the modem. It is a McArtney type BHMC3F, which mates to a model ILMC3M cable connector. The pin out of the connector is shown in Figure 20.



1: Ground

2: External Sonar TX/RX

3: External Battery (+9V to +12V)

Figure 20. Sonar Connector Pin Assignment

B. UNDERWATER COMMUNICATION SYSTEM SOFTWARE

The basic application used in this system is AModem, which is implemented by Desert Star. The other applications used in this system are DiveTerm, HyperTerminal, and DT Test. The following subsections discuss these applications.

1. DiveTerm

After compiling the AModem code, the Archimedes C Compiler creates the executable "amv112.dc" file for the 68HC11E1FN microprocessor. Downloading the "amv11.dc" file to the RBS-1 modem is accomplished through a utility program called "DiveTerm," which is run on a PC. The DiveTerm application is implemented by Desert Star. With a serial-cable connection, DiveTerm presents a "Memory Map" PC screen of the RBS-1 modem's current programmable ROM contents and allows the user to erase, download, run or select one of the applications. This software is for a host PC used to mange or control the modem and is not for modem implementation. Figure 21 shows a DiveTerm software screenshot, which shows the modem PROM contains only the AModem application while the remainder of it memory is not used.

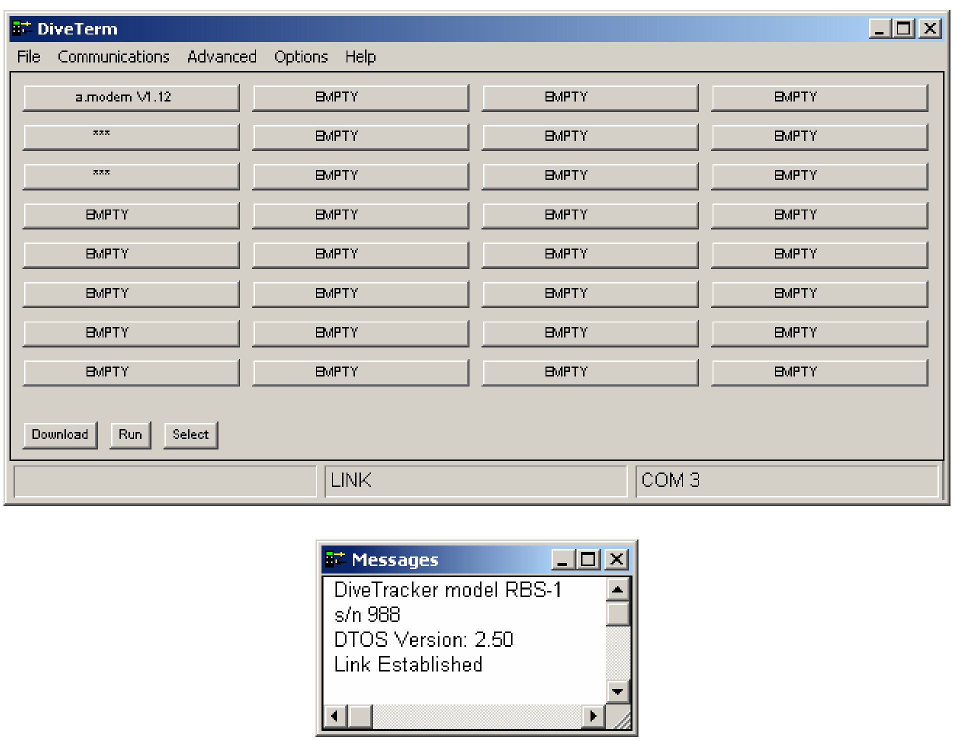


Figure 21. DiveTerm Software

2. HyperTerminal

To access the modem parameters and operate the acoustic modem, the user must access the AModem software using Hilgraeve's HyperTerminal or HyperTerminal Private Edition. For this research, HyperTerminal Private Edition is used. The user will choose an appropriate port for HyperTerminal and configure the HyperTerminal connection according to the parameters shown in Table 2. The RBS-1 modem must be turned on after running the HyperTerminal application.

Bits per second	1200
Data Bits	8
Parity	None
Stop Bits	1
Flow control	Xon/Xoff

Table 2. HyperTerminal Configuration Parameters

3. AModem

AModem is a simple modem application for the RBS-1 module implemented by Desert Star. A station that is running AModem will behave similar to a telephone modem, except that the transmission medium is water. Data received through the serial port is coded and transmitted via the transducer through the water. The transducer data received by AModem is decoded and transmitted via the module's serial port. Unlike a full duplex telephone modem, AModem is half duplex. This means that only one party can transmit data at any given time. It is up to the user's software to ensure that only one party is transmitting. If a "data collision" does occur, no party will receive valid data. Also unlike telephone modems, AModem is not restricted to two-party communication, thus a given receiver will detect data from multiple transmitters and a given transmitter may be received by multiple receivers similar to wireless amateur radio operations.

AModem code is written in the "C" programming language and linked with 68HC11 microcontroller specific libraries. An Archimedes "C" Compiler is used to compile this code with the parameters shown in Table 3. The output of the compiler is an “amv112.dc” file, which is the actual hexadecimal executable machine code that must be downloaded to the RBS-1 modem. The Archimedes “C” compiler is no longer widely available.

c-6811 –mb –z –P –e -l amodem.lst -p50 -xDFT -q amodem.c
c-6811 –mb -z –P –e –RCODE1 -l ss.lst -p50 -xDFT -q ss.c
c-6811 –mb –z –P –e -RCODE2 -l sl1.lst -p50 -xDFT -q sl1.c
c-6811 –mb –z –P –e -RCODE3 -l sl2.lst -p50 -xDFT -q sl2.c
c-6811 –mb -z –P –e –RCODE4 -l ip.lst -p50 -xDFT -q ip.c
c-6811 –mb -z –P –e -RICODE -l ih.lst -p50 -xDFT -q ih.c
Rem a6801 dtasm
A6801 jdtos
A6801 jdt20_s
xlink amodem ss sl1 sl2 ip ih jdtos -xmse -o amv112.dcu -l am.ref -p50 -f lbnk.xcl
xlink amodem ss sl1 sl2 ip ih jdt20_s -xmse -o amlcv112.dcu -l amlc.ref -p50 -f lbnk.xcl
smush amv112.dc amv112.dcu 1.00 amlcv112.dcu 1.10,1.11,2.00,2.10,2.11,2.20,2.40,2.50

Table 3. AModem Compiler Parameters

There are two types of data format implemented by the code, depending on the transmission link serviced. The Serial Data Transmission link uses the Serial Data Format and the Sonar Data Transmission link uses the Acoustic Data Format.

The Serial Data Format is for the serial-data interface. This interface works between the user and the acoustic modem. More specifically, it works between the HyperTerminal application and the acoustic modem. Serial Data Interface operates at 1,200 baud, 8 data bits, no parity bit, 1 stop bit. The 1,200 baud speed is fast enough to keep up with the fastest sonar transmission, yet slow enough to be supported by just about any device.

The Acoustic Data Format is for the acoustic data interface. This interface works between the modem and transducer. The modem transmits and receives acoustic data words consisting of one synchronization ping, four data pings and one checksum ping. Each data ping is position-coded and represents four bits of information, for a total of 16 bits (two characters). The checksum is used by the receiver to verify the integrity of each word. The modem's ability to communicate 20 bits worth of information with just six pings makes it a very energy efficient. Figure 22 shows these six pings. The acoustic modem receives and transmits 8-bit data words via the serial data interface. During transmission, the modem will pack two 8-bit serial data words in each data ping. No data is transmitted until at least two bytes have been received via the serial data interface. Each received data word is unpacked into 8-bit words, which are transmitted via the serial data interface. If the modem detects a bad checksum on an incoming acoustic data word, it will transmit "##" via the serial data link. This bad data indicator is a useful guide for adjusting the modem sensitivity and speed.

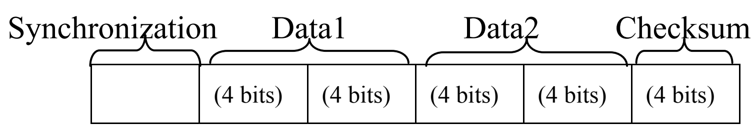


Figure 22.   Six-Ping Word

Desert Star AModem code is designed for half-duplex communication. Data is either transmitted or received at any one time. Data cannot be received and transmitted via the acoustic link at the same time. By default, the modem is in the receive mode. It switches automatically to transmit mode as soon as at least two data bytes are in its serial data buffer. The modem will remain in transmit mode until less than two bytes remain in its serial input data buffer.

4. DT Test

DT Test is a test code for the RBS-1 modem implemented by Desert Star. Transducers may be caused to ping continuously. This signal is normally clearly visible using another transducer. The DT Test can also be used to measure the ambient noise level. Figure 23 shows the DT Test screenshot and the options that can be tested. During this research the DT Test application is used to measure the appropriate threshold level of the modems that can be varied according to the environment.

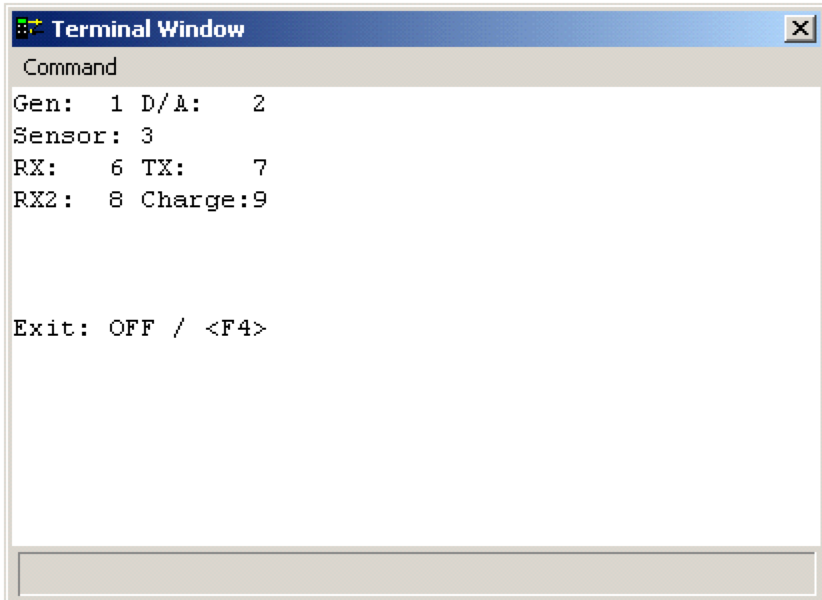


Figure 23. DT Test Screen

C. ACOUSTIC COMMUNICATION SYSTEM OPERATIONS

This section discusses the general architecture of the Desert Star AModem application.

1. Message Encoding

A two-character message sent using the AModem system is encoded as a single data packet with 20 bits of information. Of these 20 bits, eight are data0 (first character), eight are data1 (second character) and four are checksum. Figure 24 shows the data-travel schema.

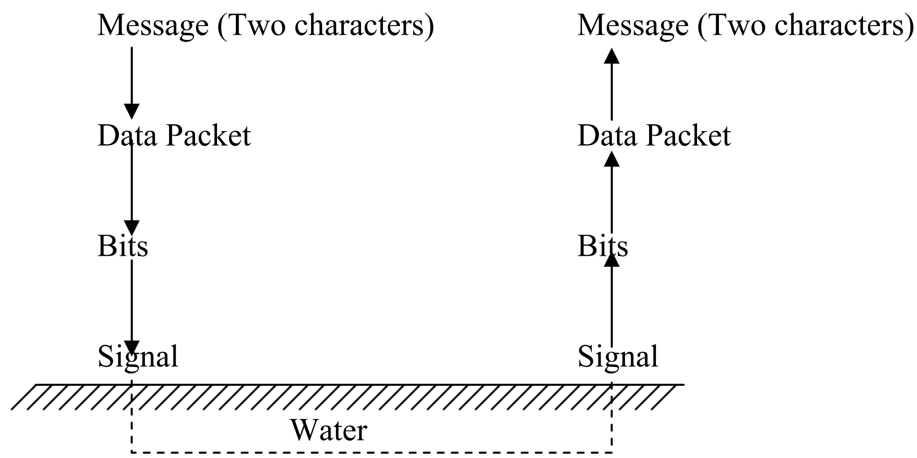


Figure 24. Data-Travel Schema

The AModem data encoding scheme is based on time, not frequency. This comment should be considered for correct CDMA implementation since most of the CDMA applications are based on frequency operations. The pings (signals) obtain their meaning according to the time that they occur referenced to a synchronization ping.

Figure 25 is a graphic representation of a message. The first ping, at 34 kHz, serves as a synchronization ping and establishes the time frame reference. The remaining five pings, which carry four bits of information each, are "pulse position coded." Pulse position coding was chosen for the AModem system because it is a very energy efficient way of coding —20 bits can be sent in just six pulses. This means that there is a specific window of fixed size (time) in which each ping must occur. Each window is further divided into 16 subwindows. Exactly when and where the ping falls into a subwindow determines its meaning. This is the binary equivalent of 0000 to 1111, 0000 being the first subwindow, 0001 being the second, and so on. The net result is that five four-bit binary values are established at the receiver. The purpose of the recovery period is to provide a sufficient time the signal to die down.

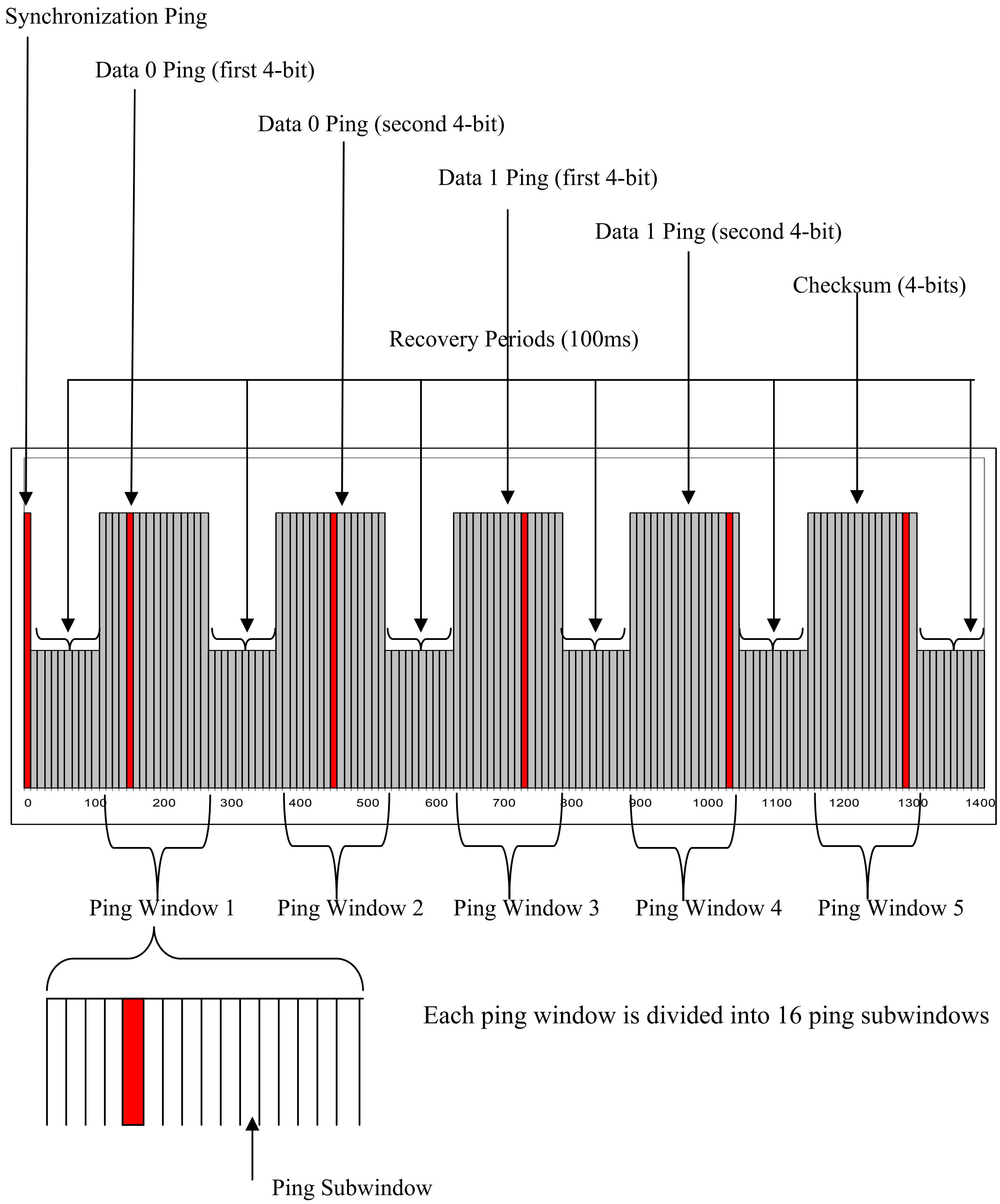


Figure 25. Graphic Representation of a Message

The Figure 25 is the exact implementation of the Speed 0 option. The other speed options and their equivalent subwindow time, recovery time, message total transmit time, nibbles transmit speed and baud speed of the system is depicted in Table 4.

Speed Option	Subwindow Time (ms)	Recovery Time (ms)	Message Total Transmit Time (ms)	Nibble Transmit Speed (nibble/sec)	Baud Speed (baud)
0	10	100	1410	3.6	14.2
1	4	40	564	8.9	35.7
2	2	20	282	17.9	71.4
3	1	10	141	35.7	142.8
4	10	600	4410	1.13	4.5
5	4	250	1824	2.7	10.9
6	4	40	564	8.9	35.7

Table 4. Transmission Speed Parameters

Message total transmit time, nibbles transmit speed and baud speed are calculated according to the equations below.

$$\begin{aligned} MessageTotalTransmitTime = {} & SubwindowTime(ms) + \\ & 5 \times (16 \times SubwindowTime(ms)) + . \\ & 6 \times RecoveryTime(ms) \end{aligned}$$

Equation 10. Message Total Transmit Time

$$NibbleTransmitTime(nibble/\sec) = \frac{5nibble \times 1000}{MessageTotalTransmitTime(ms)}.$$

Equation 11. Nibble Transmit Speed

$$BaudSpeed(baud) = \frac{20bit \times 1000}{MessageTotalTransmitTime(ms)}.$$

Equation 12. Baud Speed

Therefore the key variables for data transmission are Subwindow Time and Recovery time. Subwindow time and Recovery time are defined as constants in the sl1.c file of the AModem software system. The subwindow times are defined in that file as 10,000, 4,000, 2,000, 1,000, 10,000, 4,000, 4,000 , in microseconds. The recovery time, in microseconds, are 100,000, 40,000, 20,000, 10,000, 600,000, 250,000, 40,000.

2. Message Decoding

A six pulse message received using the AModem system is decoded as a single-data packet with 20 bits of information. When the receiver receives the first synchronization ping, it starts a timer. According to the occurrence time of the other pings in the ping-window, the data obtains its meaning.

For example, if the receiver speed option is set to 1, then each ping subwindow time is 4 ms and the recovery time is 40 ms. The receiver receives the first synchronization ping at 33898 Hz. and then starts its timer. Let's say the receiver receives the second signal 60 ms after the first ping. According to the timing system of the speed option 1, this ping occurs in the fifth subwindow of the first ping-window. Therefore, the meaning of first four bits of the first data byte is 0100. Let's say the receiver receives the third signal 180 ms after the first ping. This ping occurs in the ninth subwindow of the second ping-window. Thus, the meaning of the second four bits of the first data byte is 1000. If the fourth ping signal arrives 292 ms after the first ping, it occurs in the eleventh subwindow of the ping window 3. Thus, the meaning of the first four bits of the second data byte is 1010. Let's say the receiver receives the fifth signal 412 ms after the first ping. This ping occurs in the fifteenth subwindow of the ping window 4, corresponding to a value of 1110 for the last four bits of the second byte. Finally, let's say the receiver receives the sixth signal 516 ms after the first ping. This ping occurs in the eleventh subwindow of the ping window 5, meaning a checksum value of 1010. This example is shown in Figure 26. Thus, the received value is 48AE (hex).

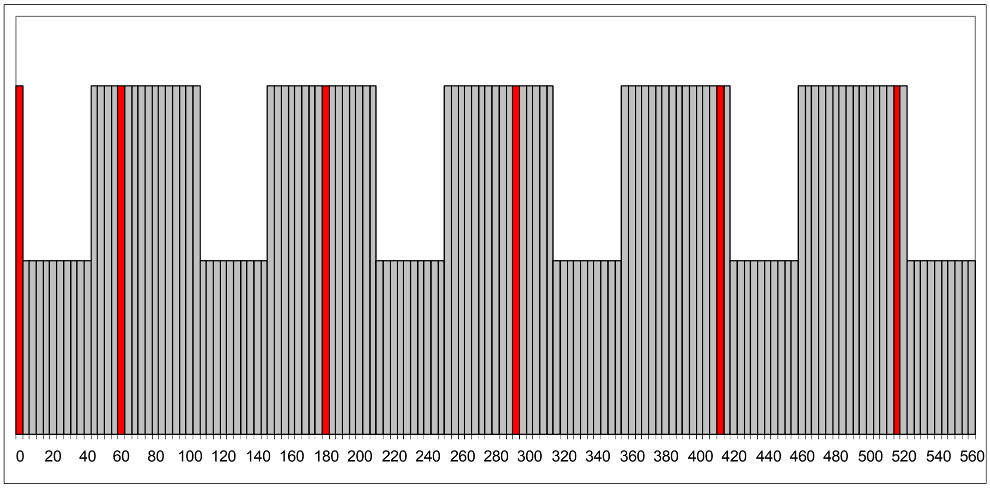


Figure 26. Message Decoding Example

3. Multichannel and Single-Channel Operation

Desert Star Amodem software uses Multichannel operation if the speed options are 0, 1, 2, or 3.

In a multichannel transmit operation, the transmitter transmits an analog signal frequency at 33,898 Hz for the synchronization ping and then transmits another analog signal at 36,364 Hz for the first four-bit ping, changes the frequency for the next ping, and so on. The transmitter frequency sequence loop for each ping is shown in Table 5.

Ping 1	Ping 2	Ping 3	Ping 4	Ping 5	Ping 6
33898 Hz	36364 Hz	38462 Hz	40816 Hz	36364 Hz	38462 Hz

Table 5. Multichannel Transmitter Frequency Sequence

The transmitter frequencies are defined as constants in the sl1.c file:

Constant “0” is used for 33,898 Hz.

Constant “1” is used for 36,364 Hz.

Constant “2” is used for 38,462 Hz.

Constant “3” is used for 40,816 Hz.

In a multichannel receive operation, the first ping is received at 28898 ± 5000Hz and the second ping is received at 31,364 ± 5,000Hz and so on. The receiver modem uses super heterodyning process that is the received signal is modulated with a predetermined analog signal 5KHz lower in frequency. The result is a 5KHz signal which is evaluated for the presence of the ping pulse.

The receiver frequency sequence loop for each ping is shown in Table 6.

Ping 1	Ping 2	Ping 3	Ping 4	Ping 5	Ping 6
28898± 5000Hz	31364 ± 5000Hz	33462 ± 5000Hz	35816 ± 5000Hz	31364 ± 5000Hz	33462± 5000Hz

Table 6. Multichannel Receiver Frequency Sequence

The receiver frequency sequence is defined as a constant in the sl1.c file.

Constant "-5" is used for 28,898 Hz.

Constant "-4" is used for 31,364 Hz.

Constant "-3" is used for 33,462 Hz.

Constant "-2" is used for 35,816 Hz.

Single-Channel operation is used with the speed options 4, 5 and 6.

In a single-channel transmit operation; every ping of the message is transmitted at 33,898 Hz. See Table 7.

Ping 1	Ping 2	Ping 3	Ping 4	Ping 5	Ping 6
33898 Hz	33898 Hz	33898 Hz	33898 Hz	33898 Hz	33898 Hz

Table 7. Single Channel Transmitter Frequency Sequence

In a single-channel receive operation, every ping of the message is received at 28,898 ± 5,000Hz. See Table 8.

Ping 1	Ping 2	Ping 3	Ping 4	Ping 5	Ping 6
28898± 5000Hz	28898± 5000Hz	28898± 5000Hz	28898± 5000Hz	28898± 5000Hz	28898± 5000Hz

Table 8. Single-Channel Receiver Frequency Sequence

4. Analog Data Specifications

For every ping, the modem transmits an analog signal at a specified frequency. If the transmitter uses speed option 1 and the time occurrence of the pings are like the example given above in the Message Decoding subsection, then the analog signal occurs as in Figure 27 shown below.

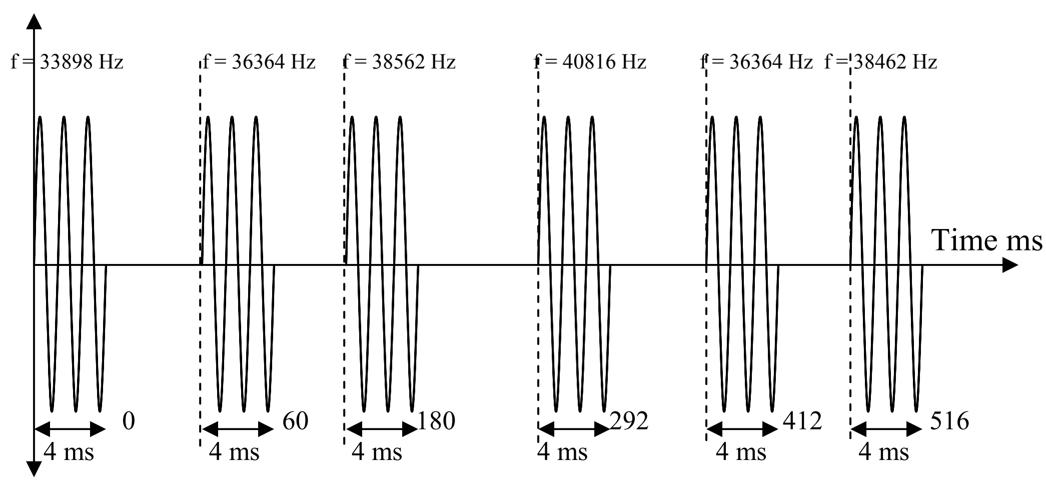


Figure 27. Analog Data Specification

These analog signals occur for 4 ms by a default setting of the Power Length option

5. Synchronization Ping Consideration

The synchronization ping is used only to indicate the beginning of the 20 bit message. AModem uses an analog signal at 33898 Hz. as synchronization for both the multichannel and single-channel operation. This is not an actual synchronization like that used in several other protocols, like Ethernet. Every message has its own synchronization ping. After transmitting a message, the next message again starts with the synchronization ping and is followed by 4 data pings and 1 checksum ping.

6. AModem System Problems

When communication is unsuccessful, one of three situations may happen: either the ping does not get through at all, or it gets through but is in the wrong subwindow, or there is a noise pulse generated by some external source that was mistakenly recognized as a ping.

From an acoustic point of view, a ping may reach its destination by traveling any of many paths. This may cause variations in the arrival time, causing the ping to be heard more than once. Additionally, the environment may foster the development of echoes, again causing the ping to be heard repeatedly. To deal with these problems, only the first ping arriving at the receiver is considered valid. Then, to allow multiple pings and echoes on the same frequency to die down, each window is followed by a "recovery period" during which the transmitter is quite.

In an effort to improve reliability further, different frequencies are used. The Desert Star's AModem software synchronization ping is always at 33,898 Hz, but the second ping will be at a substantially higher frequency. In all, four frequencies are used and the sequence bounces back and forth between high and low to maximize frequency separation. By using set recovery times and different frequencies, the likelihood that any one transmitted ping will be interpreted correctly is greatly enhanced.

Whether or not the ping is received is a function only of its strength in relation to the threshold level set for the receiver. Lowering the threshold level, which is one of the parameters in the code, also makes the system more susceptible to ambient noise. Additionally, lowering the threshold increases the amount of time that must be allowed for echoes to die down. The output power of the transmitter directly affects the signal strength at the receiver. The maximum output power of the transducers, as commonly set up in the AModem system, is 186 dB reference one micro Pascal at one meter.

The final cause of trouble, a noise pulse generated by some external source, causes the binary value to be reduced because it precedes the true pulse.

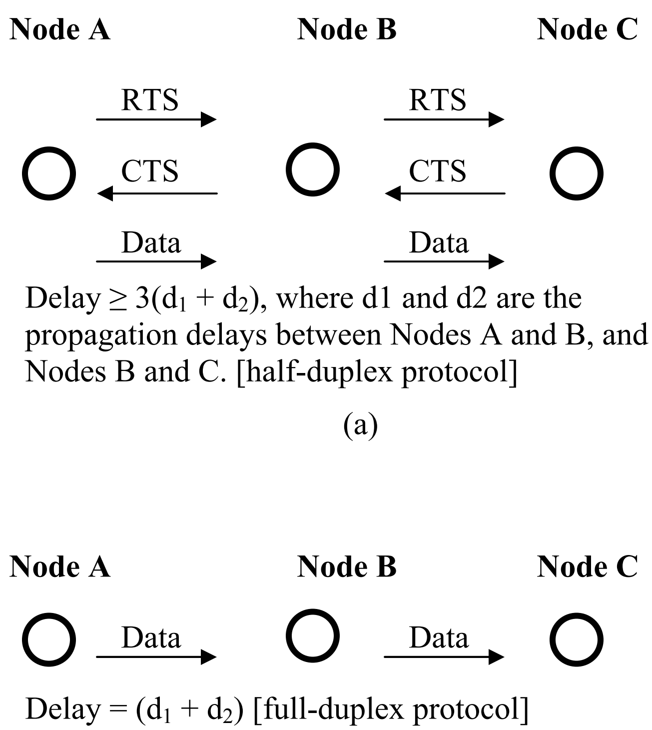
D. FULL-DUPLEX COMMUNICATION BASICS

Currently, most UANs still use half-duplex communications with a contention avoidance protocol. The use of a full-duplex network may greatly enhance the overall efficiency of the UAN. The purpose of this section is to show the advantages of a full-duplex underwater network. It will also detail the hardware setup of underwater acoustic modems in a full-duplex configuration.

A full-duplex UAN uses a data transmission mode that allows data to be transmitted in both directions at the same time. This type of network is analogous to a two-lane road where traffic can go in opposite directions at the same time. The data being transferred will be split between the network channels and must fully load the channels to ensure that the use of the network does not decrease. In order to ensure that the channels can carry concurrent data streams, the UAN will have to use a time division multiple access (TDMA), frequency division multiple access (FDMA), or a code division multiple access (CDMA) scheme.

1. Comparison of Full-Duplex and Half-Duplex

Compared to a half-duplex configuration, the full-duplex network may provide a better networking environment. Half-duplex connections compound the effects of the propagation delay on data transfer latency by requiring the exchange of several control packets to establish media access. The establishment of full-duplex connections between each pair of nodes provides a means of assured access to the media without exchanging access requests prior to each traffic exchange session. [3] Using a simple half-duplex network with three nodes, A, B and C, a message transmission will be initiated when node A sends a ready-to-send message (RTS) to node B. When node B receives the RTS, it will then send a clear-to-send message (CTS). After node A receives the CTS, it will start sending its data. The same operation happens between node B and C. Therefore, the total propagation delay will be three times greater than the propagation delay between node A and B (d_1) plus node B and C (d_2). Figure 28(a) is a visual diagram of this protocol. With a half-duplex configuration, when a node is transmitting, it uses the entire bandwidth of the channel. When using a full-duplex network, the bandwidth is split and communication channels are assigned to receive and to transmit data. Each node has at least one channel for transmitting and one channel for receiving data. With dedicated channels there will be no collisions and the overhead associated with the half-duplex contention based protocol is eliminated. Without using any type of multiplexing, these dedicated channels will reduce the efficiency of the data transfer because the bandwidth has been split. However, by using TDMA, FDMA, or CDMA, this problem may be minimized and the full-duplex network will be able to use the entire bandwidth just like a half-duplex network. As can be seen from the Figure 28(b), full-duplex protocol delay will be equal to the delay between node A and B (d_1) plus the delay between node B and C (d_2)



(b)

Figure 28. Message Delay due to protocol [From Ref. 3]

A full-duplex network will provide a smaller total data transfer time as long as the transmission of the data is constant between the two configurations. In fact, the speed is doubled because of the reduced propagation time. But, even if the transmission rate is lower, the full-duplex configuration will still have a more responsive data delivery. In both guided media and traditional wireless settings, the propagation time is normally negligible and is often ignored. "However, propagation delays in water are significant and play a dominant role in the speed that the data is transferred. Using this information, a full-duplex UAN was configured for testing [3]."

2. Design Solution for Full-Duplex Communication

Full-duplex communication is established with four RBS-1 modems. Each computer is assigned two of the RBS-1 modems: one is for transmission purposes and the other is used for receiving purposes. Figure 29 demonstrates the full-duplex design of the system in a bucket. Modem-1 is the transmitter, and Modem-2 is the receiver for one computer. Modem-3 is the transmitter, and Modem-4 is the receiver for another computer.

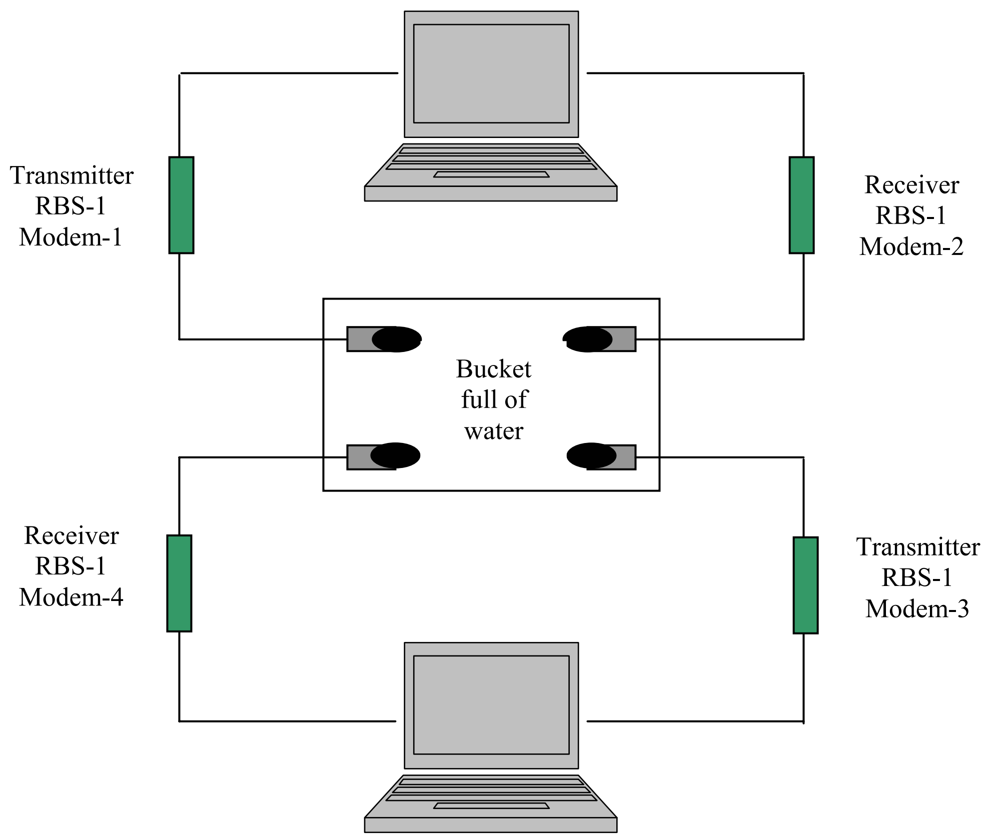


Figure 29. Full-Duplex Design

The software downloaded to each modem will be explained in Chapter IV. The figure above illustrates one of the possible design solutions. The key principle of this solution demonstrates that a given transmitter is sending its data, and that only the corresponding receiver is receiving it. For example, during the scenario when Transmitter RBS-1 Modem-1 is sending data, only Receiver RBS-1 Modem-4 must receive this data. The other receiver, RBS-1 Modem-2, must not receive the Transmitter RBS-1 Modem-1's data. Another key point is while both transmitter RBS-1 Modem-1 and RBS-1 Modem-3 are transmitting their data simultaneously, corresponding receivers must receive their data without any error.

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IV. CDMA IMPLEMENTATION

A. CDMA

CDMA is a multiplexing technique used with spread spectrum. Different users can use the channel simultaneously by assigning different spreading code sequences to them. Therefore there is no physical separation in time or in frequency between signals from different users. The physical channel is divided into many logical channels by the spreading codes.

The three common types of CDMA are Direct-Sequence (DS) CDMA, Frequency Hopping (FH) CDMA and Time Hopping (TH) CDMA. Details of DS-CDMA, FH-CDMA, TH-CDMA and the basic CDMA principles will be discussed in the next sections. The hybrid CDMA systems include all CDMA systems that combine two or more of the mentioned spread-spectrum modulation techniques. Therefore the four possible hybrid systems are DS/FH, DS/TH, FH/TH, and DS/FH/TH.

1. Basic CDMA Principle

The CDMA basic principle is explained with an example. Bit data rate D is the rate of the data signal. Each bit is broken into k chips according to a fixed pattern that is specific to each user, called the "user's code." The new channel has a chip data rate of kD chips per second. Let's assume $k=6$. It is simplest to characterize a code as a sequence of 1s and -1s. There are three user's code for user A, B, and C, each of which is communicating with the same base station receiver, R. Thus, the code for user A is $c_A = <1,-1,-1,1,-1,1>$. Similarly, user B has code $c_B = <1,1,-1,-1,1,1>$, and user C has $c_C = <1,1,-1,1,1,-1>$.

Let's assume user A wants to communicate with the base station R. The base station is assumed to know A's code. For simplicity, we assume that communication is already synchronized so that the base station knows when to look for codes. If A wants to send a 1-bit, A transmits its code as a chip pattern $<1,-1,-1,1,-1,1>$. If a 0 bit is to be sent, A transmits the complement (1s and -1s reversed) of its code, $<-1,1,1,-1,1,-1>$. At the base station, the receiver decodes the chip patterns. In our simple version, if the receiver R receives a chip pattern $d =< d1, d2, d3, d4, d5, d6 >$, and the receiver is seeking to communicate with a user u so that it has at hand u's code, $< c1, c2, c3, c4, c5, c6 >$, the receiver performs electronically the following decoding function.

$$S_u(d) = d1 \times c1 + d2 \times c2 + d3 \times c3 + d4 \times c4 + d5 \times c5 + d6 \times c6 .$$

The subscript u on S simply indicates that u is the user that the decoding function is for. Suppose the user u is A. If A sends a 1-bit, then *d* is $< 1, -1, -1, 1, -1, 1 >$ and the computation using S_A becomes

$$S_A(1, -1, -1, 1, -1, 1) = 1 \times 1 + (-1) \times (-1) + (-1) \times (-1) + $$
$$1 \times 1 + (-1) \times (-1) + 1 \times 1 = 6 .$$

If A sends a 0-bit, which corresponds to $d =< -1, 1, 1, -1, 1, -1 >$, we get

$$S_A(-1, 1, 1, -1, 1, -1) = (-1) \times 1 + 1 \times (-1) + 1 \times (-1) + $$
$$(-1) \times 1 + 1 \times (-1) + (-1) \times 1 = -6 .$$

It is always the case that $-6 \leq S_A(d) \leq 6$ no matter what sequence of -1s and 1s that d is, and that the only d's resulting in the extreme values of 6 and -6 are A's code and its complement, respectively. So if S_A produces a +6 we say that we have received a 1 bit from A; if S_A produces a -6 we say that we have received a 0-bit from user A; otherwise, we assume that someone else is sending information or there is an error. For example if user B sends a 1-bit and we try to receive it with S_A, d becomes $< 1, 1, -1, -1, 1, 1 >$.

$$S_A(1,-1,-1,1,-1,1) = 1\times 1 + 1\times(-1) + (-1)\times(-1) +$$

$$(-1)\times 1 + 1\times(-1) + 1\times 1 = 0 .$$

Thus, the unwanted signal (from B) does not show up at all. You can easily verify that if B had sent a 0 bit, the decoder would produce a value of 0 for S_A again. This means that if the decoder is linear and if A and B transmit signals s_A and s_B, respectively, at the same time, then $S_A(s_A + s_B) = S_A(s_A) + S_A(s_B) = S_A(s_A)$ since the decoder ignores B when it using A's code. The codes of A and B that have the property, $S_A(c_B) = S_B(c_A) = 0$, are called orthogonal. Such codes are very nice to have but there are only a few of them with respect to the total combinations of 1's and -1's for the chip length. More common is the case when $S_X(c_Y)$ is small in absolute value when $X \neq Y$. Then it is easy to distinguish between the two cases when $X = Y$ and when $X \neq Y$. In our example $S_A(c_C) = S_C(c_A) = 0$ but $S_B(c_C) = S_C(c_B) = 2$. In the latter case, the C signal would make a small contribution to decode a signal instead of 0. Using the decoder, S_u, the receiver can sort out a transmission from u even when there may be other users broadcasting in the small cell. Table 9 summarizes the example from the preceding discussion.

User A	1	-1	-1	1	-1	1
User B	1	1	-1	-1	1	1
User C	1	1	-1	1	1	-1

(a) User's Code

Transmit (data bit = 1)	1	-1	-1	1	-1	1	
Receiver Codeword	1	-1	-1	1	-1	1	
Multiplication	1	1	1	1	1	1	= 6

Transmit (data bit = 0)	-1	1	1	-1	1	-1	
Receiver Codeword	1	-1	-1	1	-1	1	
Multiplication	-1	-1	-1	-1	-1	-1	= -6

(b) Transmission from A

Transmit (data bit = 1)	1	1	-1	-1	1	1	
Receiver Codeword	1	-1	-1	1	-1	1	
Multiplication	1	-1	1	-1	-1	1	= 0

(c) Transmission from B, receiver attempts to recover A's transmission

Transmit (data bit = 1)	1	1	-1	1	1	-1	
Receiver Codeword	1	1	-1	-1	1	1	
Multiplication	1	1	1	-1	1	-1	= 2

(d) Transmission from C, receiver attempts to recover B's transmission

B (data bit = 1)	1	1	-1	-1	1	1	
C (data bit = 1)	1	1	-1	1	1	-1	
Combined Signal	2	2	-2	0	2	0	
Receiver Codeword	1	1	-1	-1	1	1	
Multiplication	2	2	2	0	2	0	= 8

(e) Transmission from B and C, receiver attempts to recover B's transmission

Table 9. CDMA Example[From Ref. 15]

In practice, the CDMA receiver can filter out the contribution from unwanted users, or they appear as low-level noise. However, if there are too many other users competing for the channel, or if the signal power of one competing signal is too high, perhaps because the competing user is much closer to the receiver (the "near/far" problem), the system may break down.

2. Frequency Hopping-Code Division Multiple Access

FH-CDMA is based on a narrowband Frequency Division Multiplexing system in which an individual user's transmission is spread out over a number of channels over time (the channel choice is varied in a pseudorandom method). The transmitter and receiver system architecture of FH-CDMA is shown in Figure 30.

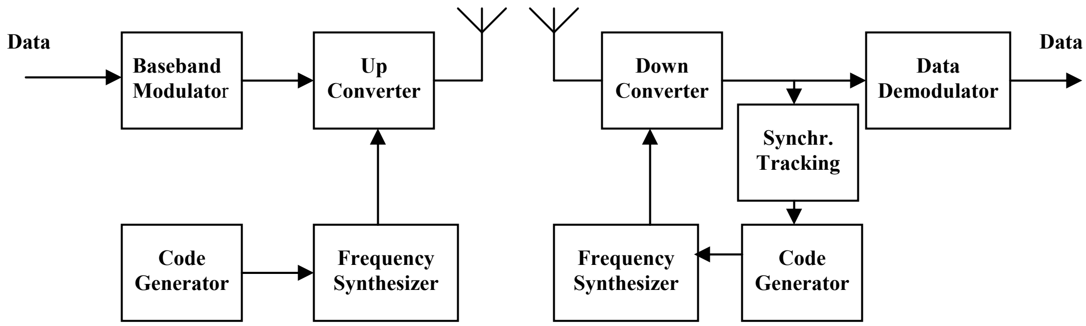

Figure 30. FH-CDMA Transmitter and Receiver System Architecture. [From Ref. 15]

The data signal is baseband-modulated on a carrier frequency. Several modulation techniques can be used for this, but it does not really matter which one is used for the application of frequency hopping. Usually frequency shift keying (FSK) modulation is used for digital signals and FM modulation for analog signals. Using a fast-frequency synthesizer controlled by the code signal, the carrier frequency is converted up to the transmission frequency.

The receiver process is the inverse of a transmitter. Using a locally generated code sequence, the received signal is converted down to the baseband-modulated carrier. The data are recovered after (baseband) demodulation. The synchronization/tracking circuit ensures that the hopping of the locally generated carrier synchronizes to the hopping pattern of the received carrier so the signal can be correctly despread.

If the number of hops is (much) greater than the data rate, it is called fast-frequency-hopping (F-FH) CDMA protocol. Figure 31 shows an MFSK fast frequency hopping example. The MFSK signal is translated to a new frequency every Tc seconds by modulating the MFSK signal with the FHSS carrier signal. For the data rate, R, the duration of a bit is $T = 1/R$ and the duration of the signal element is Ts. In this case, the carrier frequency changes a number of times during the transmission of a bit, so that one bit is transmitted in different frequencies and therefore $Tc < Ts$. If the number of hops is much smaller than the data rate, it is called slow frequency-hopping (S-FH) CDMA protocol. In this case, multiple bits are transmitted at the same frequency and, therefore, $Tc \geq Ts$. Figure 32 shows an example of MFSK slow-frequency hopping.

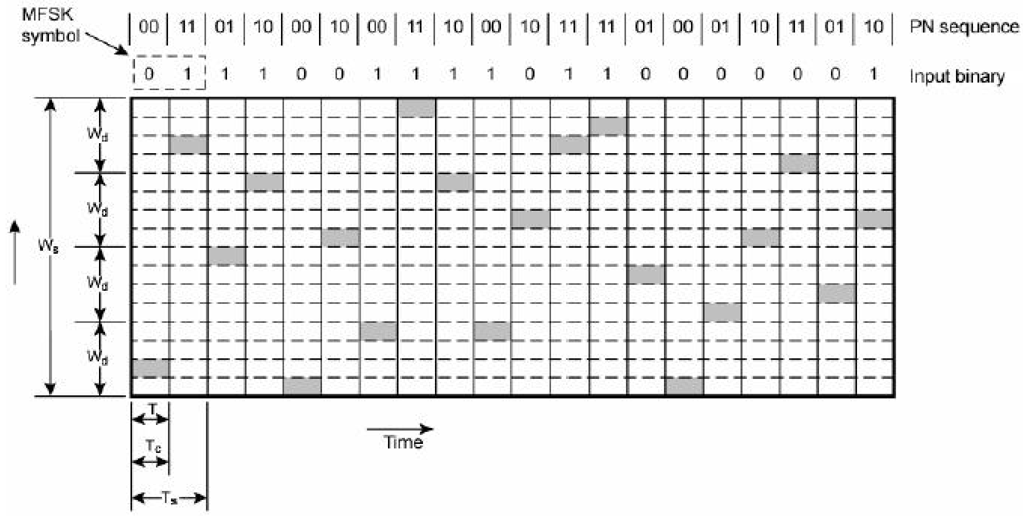

Figure 31. An Example of Fast-Frequency Hopping CDMA with MFSK Modulation [From Ref. 15]

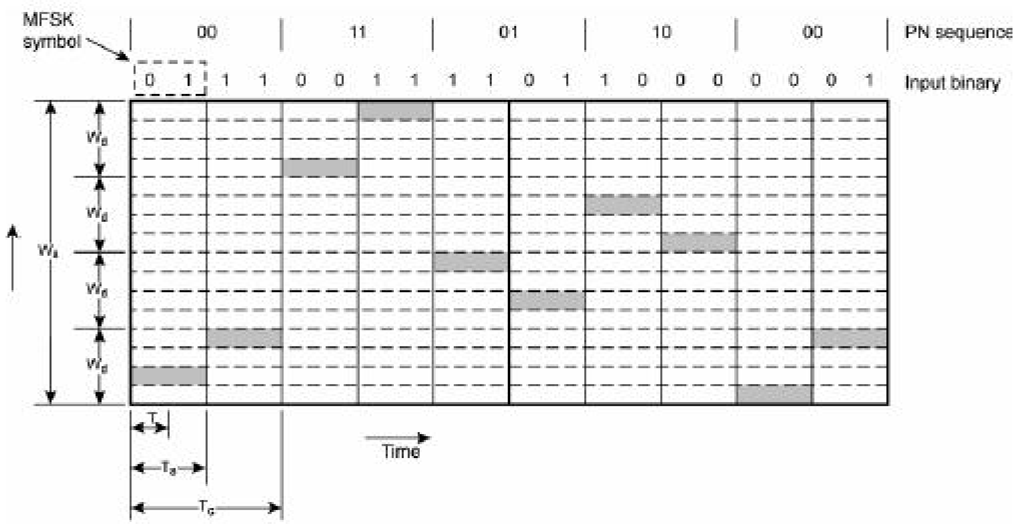

Figure 32. An Example of Slow-Frequency Hopping CDMA with MFSK Modulation [From Ref. 15]

3. Direct Sequence-Code Division Multiple Access

DS-CDMA spreads the narrowband user signal over the full spectrum by multiplying it by a very wide bandwidth signal (W). This is done by taking every bit in the user stream and replacing it with a pseudonoise (PN) code (a longer bit sequence called the “chip rate”). The codes are orthogonal or near orthogonal. The definitions of the term orthogonal and near orthogonal will be discussed in the Spreading Sequence subsection. The transmitter and receiver system architecture of DS-CDMA with coherent BPSK is shown in Figure 33 and Figure 34.

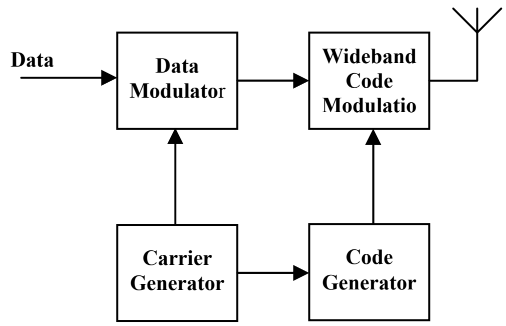

Figure 33. DS-CDMA Transmitter System Architecture [From Ref. 15]

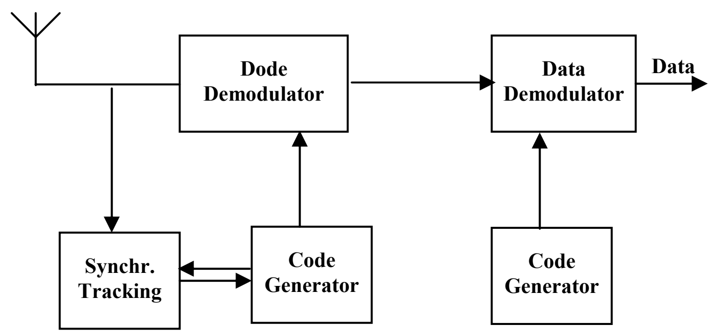

Figure 34. DS-CDMA Receiver System Architecture [From Ref. 15]

The DS-CDMA signal resulting from the transmitter is shown in Figure 35. In this figure, ten code signals per information signal are transmitted (the code chip rate is 10 times the information chip rate), so the processing gain is equal to 10. In practice, the processing gain is much larger (in the order of 10^2 to 10^3).

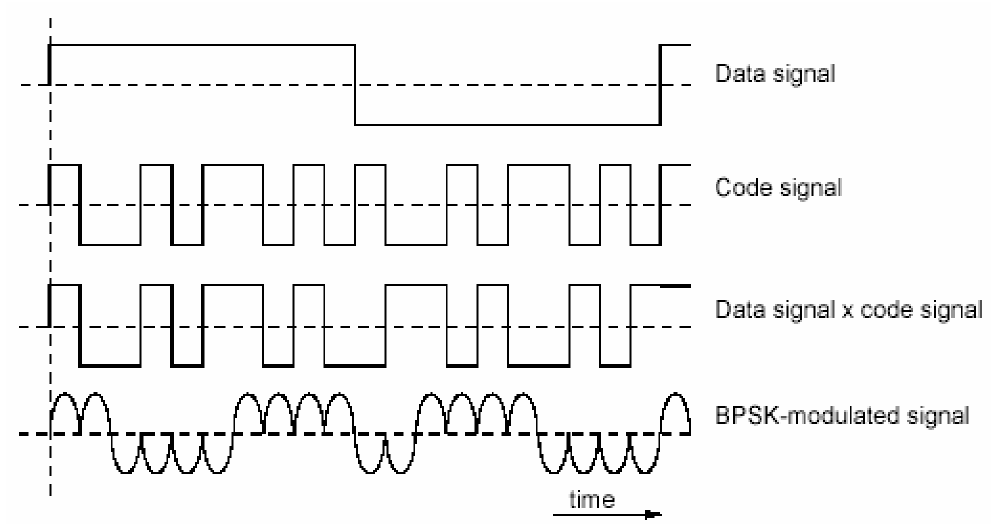

Figure 35. Generation of BPSK Modulated DS-CDMA Signal [From Ref. 15]

After transmission of the signal, the receiver uses coherent demodulation to despread the spread-spectrum signal using a locally generated code sequence. To achieve the despreading operation, the receiver must not only know the code sequence used to spread the signal, but must also synchronize the locally generated code sequence with the received signal. This synchronization must be accomplished at the beginning of the reception and maintained until the whole signal is received. The synchronization/tracking block performs this operation. After despreading, a data-modulated signal results, and after demodulation the original data are recovered.

4. Time-Hopping Code Division Multiple Access

Time Hopping is like pulse modulation, with the transmitter being keyed by the code sequence. Only the designated transmitter and receiver know the series of code used to transmit and receive the data. In the TH-CDMA protocols, the data signal is transmitted in rapid bursts at time intervals determined by the code assigned to the user. Since it is vulnerable to interference, time hopping should be combined with direct sequence or frequency hopping.

The time axis is divided into frames and each frame is divided into M equal-duration time slots. During each frame, each user will transmit in one of the M time slots as determined by the code signal assigned to the user. Since a user transmits all of its data in one, instead of M time slots, the frequency the user needs is increased by a factor M. A block diagram of a TH-CDMA system is given in Figure 36.

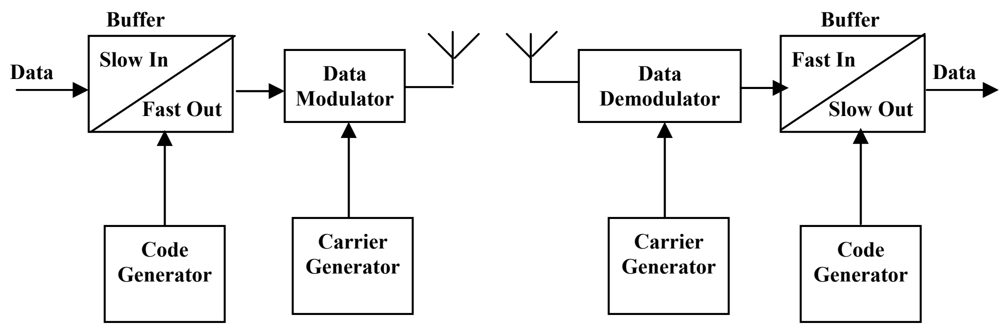

Figure 36. TH-CDMA Block Diagram

Figure 37 shows the time-frequency plot of a TH-CDMA system with 16 time slots in each frame. During the first frame, the transmitter that is assigned the code sequence 0101 transmits its data. Likewise, during the second fame, the transmitter that is assigned 0110 code sequence transmits its data and finally during the third frame the transmitter that is assigned a 0000 code sequence transmits its data. These code sequences are orthogonal to each other, as discussed in the Spreading Sequence section of this chapter.

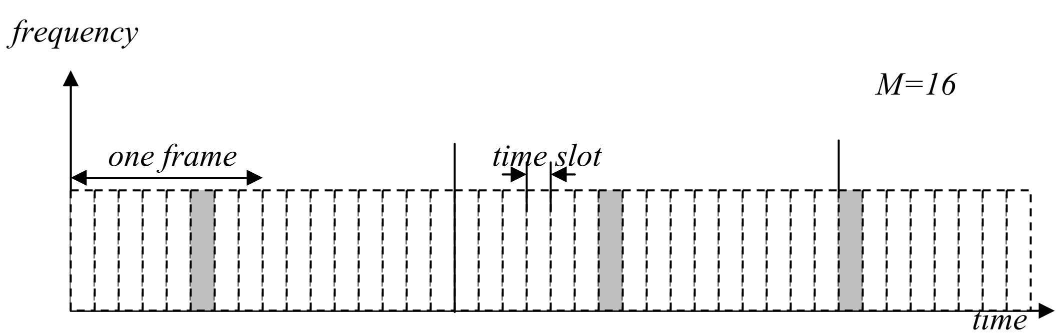

Figure 37. Time-Frequency Plot of a TH-CDMA System

5. The Comparison of the CDMA Techniques

FH-CDMA protocols have a number of specific properties that we can divide into advantages and disadvantages behavior.

The advantages are

- With FH-CDMA, synchronization is much easier than with DS-CDMA. Synchronization has to be within a fraction of the hop time. Since spectral spreading is not obtained by using a very high hopping frequency, but by using a large hop-set, the hop time will be much longer than the chip time of a DS-CDMA system. Therefore, an FH-CDMA system allows a larger synchronization error.

- Since we can make the frequency synthesizer easily skip over certain parts of the spectrum, the different frequency bands that an FH signal can occupy do not have to be contiguous. Combined with the easier synchronization, this allows much higher spread-spectrum bandwidths.

- The probability of multiple users transmitting in the same frequency band at the same time is small because FH-CDMA is an avoidance spread-spectrum system. The longer the PN sequence the smaller the probability of transmitting in the same frequency band at the same time. If a user far from the base station transmits, it is received by the base station even if users close to the base station are transmitting, since those users are probably transmitting on other frequencies. Therefore, the near-far performance is much better than that of DS.

- Because of the larger possible bandwidth that a FH system can employ, it offers a higher possible reduction of narrowband interference than a DS system.

The disadvantages are

- It is necessary to have a very sophisticated frequency synthesizer.

- When changing frequency bands lead to an increase in the frequency band occupied, an abrupt change of the signal occurs. To avoid this, the signal has to be turned off and on when changing frequency.

- Because of the problems in maintaining phase relationship during hopping, coherent demodulation is difficult.

The DS-CDMA protocols have a number of specific properties that we can divide into advantages and disadvantages.

The advantages are

- The generation of the coded signal is easy. It is done by simple multiplication.
- The frequency synthesizer (carrier generator) is simple, since only one carrier frequency must be generated.
- Coherent demodulation of the spread-spectrum signal is possible.
- No synchronization among the users is necessary.

The disadvantages are

- Synchronization must take place within a fraction of the chip time. It is not easy to acquire and to maintain the synchronization of the locally generated code signal and the received signal.
- The locally generated code sequence and the received code sequence must be synchronized within a fraction of the chip time for correct reception. This combined with the non-availability of large contiguous frequency bands practically limits the spread bandwidth to 10 to 20 MHz.
- The power received from users close to the base station is much higher than that received from users further away. Since a user continuously transmits over the whole bandwidth, a user close to the base will constantly create a lot of interference for users far from the base station, making their reception impossible. This near-far effect is solved by applying a power control algorithm so that the base station receives all the users with the same average power. However, this control proves to be quite difficult.

The TH-CDMA protocols have a number of specific properties that we can also divide into advantages and disadvantages.

The advantages are

- Implementation is simpler than that of FH-CDMA protocols.

- It is a very useful method when the transmitter is average-power limited but not peak-power limited since the data are transmitted is short bursts at high power.
- As with the FH-CDMA protocols, the near-far problem is much less of a problem since TH-CDMA is an avoidance system, so most of the time a terminal far from the base station transmits alone, and is not hindered by transmissions from stations close by.

The disadvantages are

- It takes a long time before the code is synchronized, and the time is short in which the receiver must perform the synchronization.
- As discussed before, after each ping, recovery time is required. If multiple transmissions occur and there is not enough time for recovery, a lot of data bits are lost, so a good error-correcting code and data interleaving are necessary.

B. SPREADING SEQUENCE

There are two spreading sequence categories: PN sequence and orthogonal codes. PN sequence is widely used in FH-CDMA systems. DS-CDMA systems usually use orthogonal codes. This section will discuss the orthogonal codes used in this thesis.

For a CDMA application, each user uses one sequence in the set as a spreading orthogonal code. There are different ways of determining orthogonal codes. The well-known ones are Walsh Code [15], Variable-Length Orthogonal Codes, and Hadamard Code.

A pair of codes is said to be orthogonal if the cross correlation is zero.

For two m-bit codes: $x_1, x_2, x_3, ...x_m$ and $y_1, y_2, y_3, ...y_m$:

$$R_{xy}(0)=\sum_{i=1}^{m} x_i . y_i = 0 .$$

Equation 13. Cross Correlation of Orthogonal Series

For example: $x = 0,0,1,1$ and $y = 0,1,1,0$. The 0's are -1, and 1 stays as is. Then:

$x = -1-111$

$y = -111-1$

$R_{xy}(0) = 1-1+1-1 = 0$.

The product of two m-bit codes may not be zero for every pair of signals even when the average over many pairs of such signals is zero. Such random signals are said to be *near-orthogonal* to emphasize that their products are zero in the mean but not identically zero for all signal pairs [18].

1. Walsh Codes

Walsh codes are the most common orthogonal codes used in CDMA applications. They are used for this thesis. In 1923, J.L. Walsh introduced a complete set of orthogonal codes. To generate a Walsh code the following two steps must be followed:

- Represent a N x N matrix as four quadrants (start off with 2x2)
- Make the first, second and third quadrants identical and invert the fourth

b	b	1	1	0	0	Code 0
b	b'	1	0	0	1	Code 1

2 Codes = 1 1 and 1 0   2 Codes = 0 0 and 01

b	b	b	b	1	1	1	1	0	0	0	0
b	b'	b	b'	1	0	1	0	0	1	0	1
b	b	b'	b'	1	1	0	0	0	0	1	1
b	b'	b'	b	1	0	0	1	0	1	1	0

The Walsh matrix has the property that every row is orthogonal to every other row and to the logical NOT of every other row.

Orthogonal spreading codes such as the Walsh sequence can only be used if all of the users in the same CDMA channel are synchronized to the accuracy of a small fraction of one chip. Because the cross correlation between different shifts of Walsh sequence is not zero, if tight synchronization is not provided, PN sequences are needed.

C. AMODEM CDMA MODIFICATION

This section addresses the four different types of CDMA modification that were made to the AModem application to support this thesis. These modifications are for implementing DS-CDMA, TH-CDMA, FH-CDMA and Hybrid (DS-TH) CDMA. Frequency Division Modification is not a CDMA implementation, but this highly efficient modification can be combined with the four CDMA modifications for better full-duplex communication.

1. AModem Frequency-Division Modification

The original AModem code is based on frequency hopping signaling. To solve the multipath fading problem, the AModem transmitter transmits its data using different frequencies, as mentioned above. The transmitter sends six pings using four different frequencies:

- The frequency loop hops from “channel 0” to “channel 1” for synchronization ping (ping 1) and ping 2,
- From “channel 1” to “channel 2” for ping 2 and ping 3,
- From “channel 2” to “channel 3” for ping 3 and ping 4,
- From “channel 3” to “channel 1” for ping 4 and ping 5,
- From “channel 1” to “cannel 2” for ping 5 and ping 6.

The need for frequency division modification is apparent after initial full-duplex experiments with the modems. According to these experiments, the two clearly distinguished transmitter channels are "channel 1," which operates at 36364 Hz and "channel 3," which operates at 40816 Hz. The corresponding receive frequencies are 31364±5000 Hz and 35816±5000 Hz. The "channel 0" and "channel 2" signals are not distinguishable from all the other signal frequencies that the RBS-1 modems.

The Desert Star AModem code sets the channel loop as mentioned earlier. The modification for frequency division is simply changing the channel assignment line to a specific distinguishable frequency, other than a frequency loop. Two of the modems are modified to send and to receive only with the "channel 1" frequency and the other two are modified to send and to receive only with the "channel 3" frequency. Therefore, the transmitter sends the whole six pings with the "channel 1" frequency or "channel 3" frequency. Figure 38 shows the full duplex communication with the frequency division and proper threshold and speed parameters in a bucket. The only modified source file for frequency division modification is *sl1.c*.

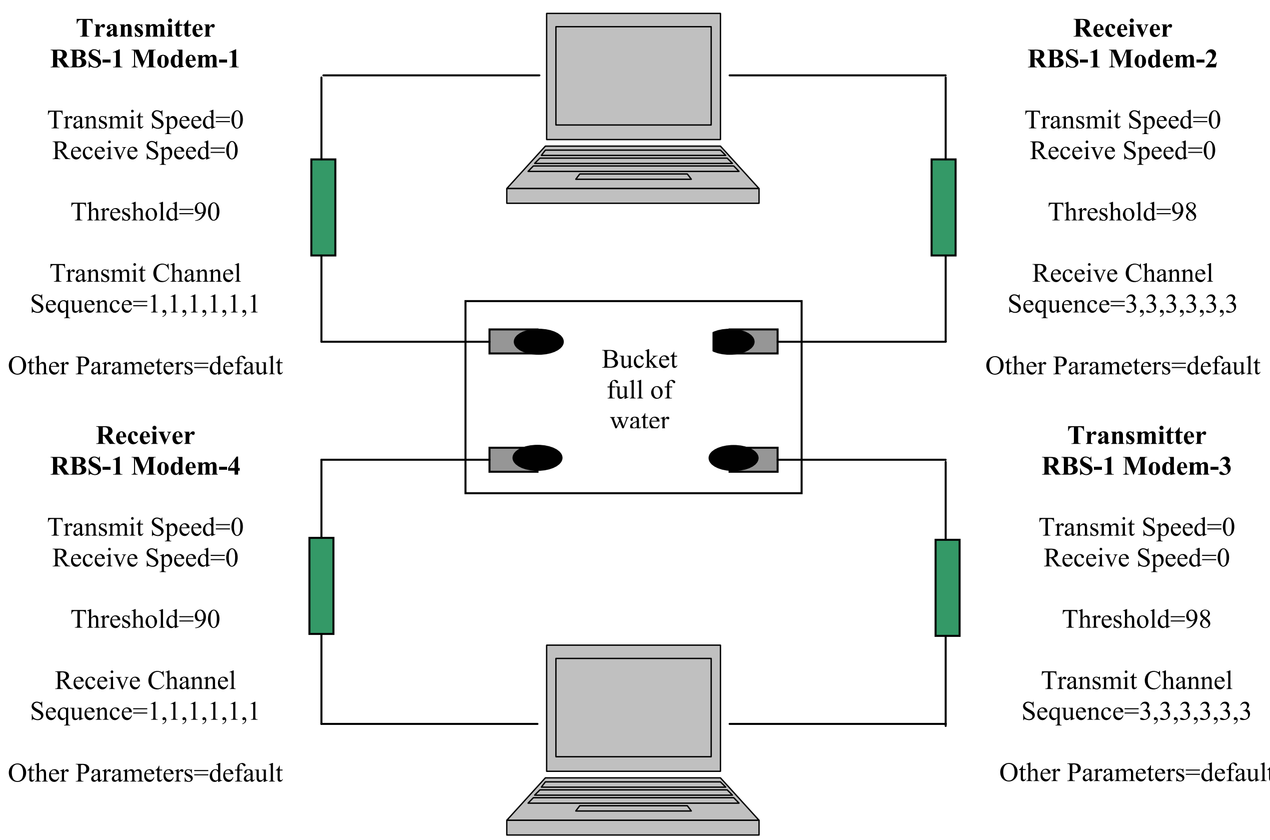

Figure 38. Full-Duplex Communication with Frequency Division in a Bucket

The threshold value, which is one of the original AModem code input parameters, is the most important factor for frequency division. The default value of the threshold is 16. If the threshold value is low (in a bucket with a threshold value of less than 50), then it is more likely to receive the other channels' signals or noise. If the threshold value is too high (in a bucket more than 50) then the receiver is not likely to receive the designated transmitter signals correctly.

The AModem Frequency Division Modification test procedure and the results will be discussed in the next chapter.

2. AModem DS-CDMA Modification

DS-CDMA implementation with current RBS-1 modem requires hardware modification because of the frequency multiplication of modulated signal and signal generated by the PN bit source. For test purposes, we will discuss the software modification that potentially could meet DS-CDMA requirements.

With the original AModem code, the only modified file is *amodem.c* for DS-CDMA modification. The DS-CDMA modification is based on the method that is explained in the section, Basic CDMA Principles.

The transmitter transmits 2 characters using 80 bits (64 data bits and 16 checksum bits) using 6 pings 4 times instead of transmitting 2 characters with 20 bits (16 data bits and 4 bits checksum) using 6 pings. Each original data bit is expanded according to the assigned 4-bit chip sequence. The chip number is very short for test purposes.

The two orthogonal chip sequences selected for this modification are "1111" and "1010" according to the Walsh Code. Two of the modems are modified to use a "1111" chip sequence for transmitting data bit "1" and "0000" for transmitting data bit "0." The other two modems are modified to use a "1010" chip sequence for transmitting data bit "1" and "0101" for transmitting data bit "0." Only the designated transmitter and receiver know the series of chips used to transmit and to receive the data. The disadvantage of this modification is transmitting speed. It is four times slower than the original code speed option parameters. Figure 39 shows the full duplex communication design with the DS-CDMA and proper threshold and speed parameters in a bucket.

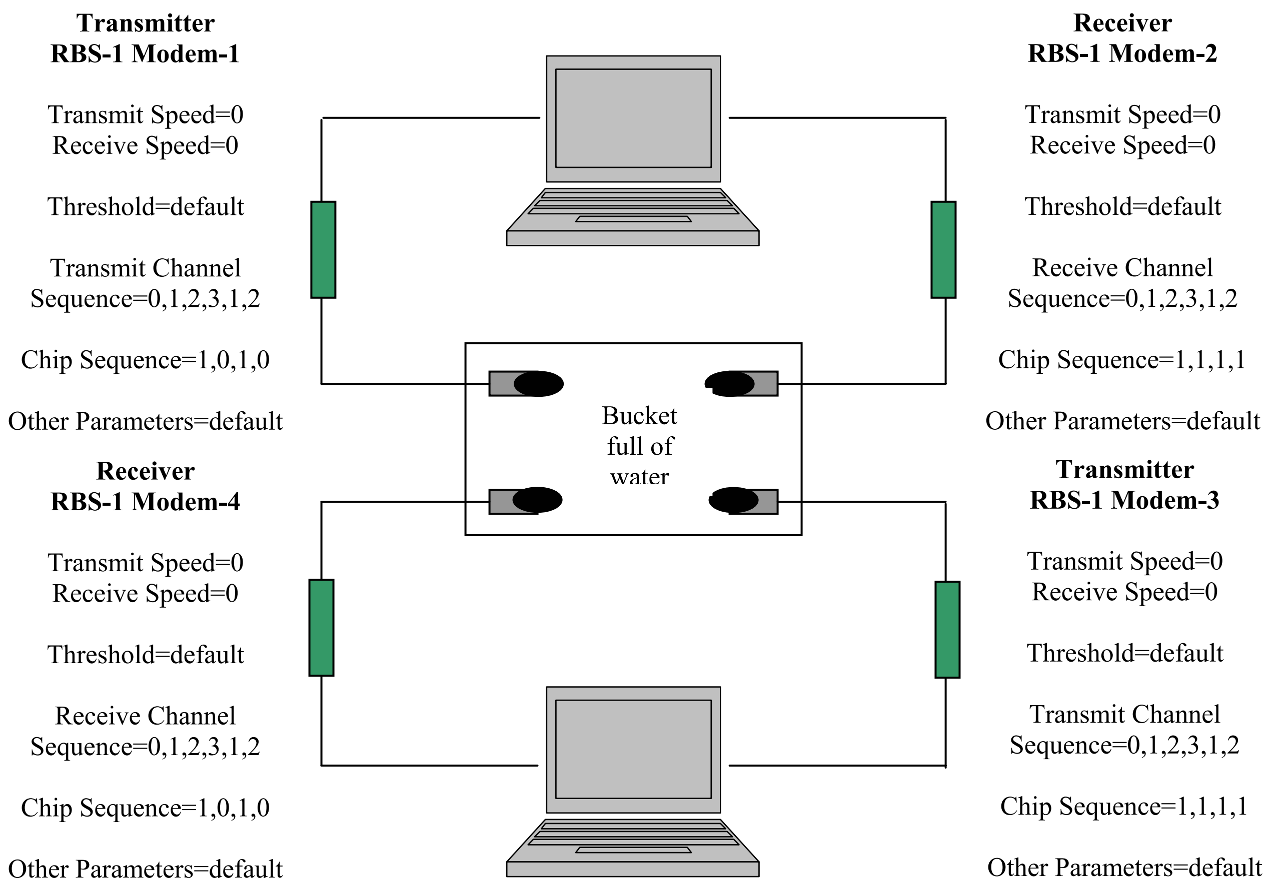

Figure 39. DS-CDMA Modification Design and Parameters in a Bucket

The AModem DS-CDMA Modification test procedure and the results will be discussed in the next chapter.

a. *Frequency Division and DS-CDMA*

This is the combination of Frequency Division Modification and DS-CDMA Modification. Once the better performance with the Frequency Division is established, the combination with DS-CDMA is worth trying.

The design figure is almost the same as the figure explained above. The only change is the frequency sequence. Instead of the frequency sequence "0,1,2,3,1,2", the two distinguishable channels are used. The "channel 1" is used for all pings with a "1,0,1,0" chip sequence and "channel 3" is used for all pings with a "1,1,1,1" chip sequence. Figure 40 shows the Frequency Division DS-CDMA modification and the parameters used with this design in a bucket. The modified source files for Frequency Division and DS-CDMA are *amodem.c* and *sl1.c*.

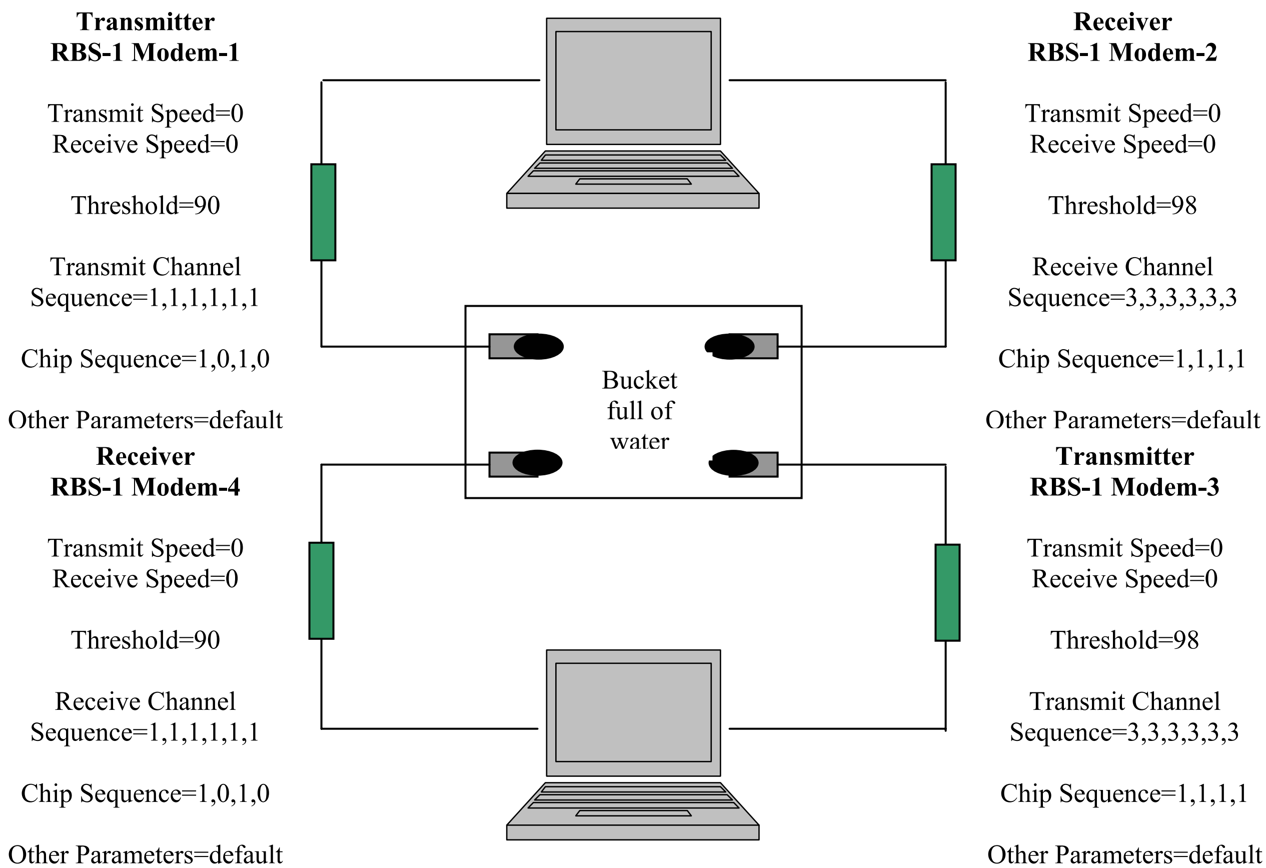

Figure 40. Frequency Division DS-CDMA Design and Parameters in a Bucket

The AModem Frequency Division DS-CDMA Modification test procedure and the results will be discussed in the next chapter.

3. AModem TH-CDMA Modification

One of the parameters of the original Desert Star AModem application is the transmission speed. The transmission speed parts of the original code are modified for TH-CDMA purpose.

There are six different speed options defined in the code as mentioned earlier. Data transmission was more reliable at the lower speeds and the default setting is 1 for both transmit and receive speeds. Table 10, [19] shows the data exchange speeds that the modem can use and the ideal environment for these speeds.

Speed	Ping Window	Equivalent Bit Rate	Work Transmit Time	Effective Data Rate	Environment
0	260 ms	15 bit/sec	1410 ms	11 baud	All. Including high-echo pools and tanks
1	104 ms	38 bits/sec	564 ms	29 baud	Harbors, shallow water, etc.
2	52 ms	77 bit/sec	282 ms	57 baud	Harbors, shallow water, etc.
3	26 ms	153 bit/sec	141 ms	114 baud	Some open ocean application and Dry Tests (transmission through air)
4	760 ms	5 bit/sec	4410 ms	4 baud	Transmit when communicating with EM-0 unit
5	314 ms	13 bit/sec	1824 ms	9 baud	Transmit when communicating with EM-0 unit
6	104 ms	38 bit/sec	564 ms	29 baud	Transmit when communicating with EM-0 unit

Table 10. Data Exchange Speeds

The TH-CDMA modification is based on speed (time) hops. Normally the time hops are determined by the chip sequence. For test purposes, random selected time hopping implementation is tested in the next chapter. Two of the modems use a “0,1,0,1,1” time-hopping sequence and the other two use a “1,1,1,0,0” time-hopping sequence. Therefore the first pair of modems uses speed 0’s parameters between the first ping and the second ping, speed 1’s parameters between the second ping and the third ping, speed 0’s parameters between the third and the fourth ping, speed 1’s parameters between the fourth and the fifth ping and speed 1’s parameters between the fifth and the sixth ping.

Likewise the second pair uses speed 1’s parameters between the first ping and the second ping, speed 1’s parameters between the second ping and the third ping, speed 1’s parameters between the third and the fourth ping, speed 0’s parameters between the fourth and the fifth ping and speed 0’s parameters between the fifth and the sixth ping.

Both the designated transmitter and receiver know the random series of time hops used to transmit the data. Figure 41 shows the full-duplex communication design with the TH-CDMA and proper parameters in a bucket. The modified files for TH-CDMA are *sl1.c* and *sl2.c*.

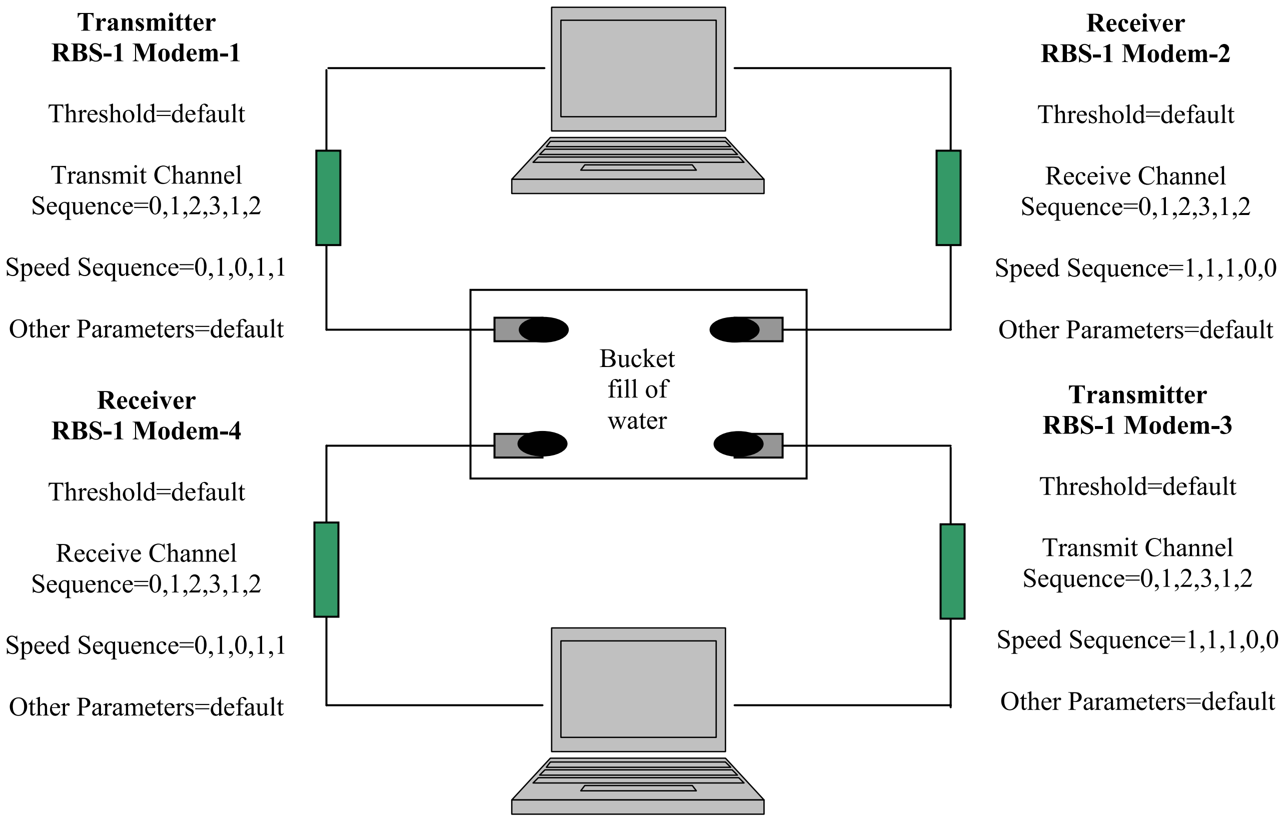

Figure 41. Frequency Division TH-CDMA Design and Parameters in a Bucket

The test environment is highly important for this modification. Although the speed option 1 is not recommended in a bucket that is a high-echo environment, random speed hopping is selected from speed 0's and speed 1's for test purposes. However, the higher speed options like "speed 1" does not cause problems in a lake or harbor. Therefore, the speed sequence can be selected from the speed option 0 or 1 for the test in a lake without a problem.

a. Frequency Division and TH-CDMA

This is the combination of Frequency Division Modification and TH-CDMA Modification.

The design figure is almost the same as the TH-CDMA figure explained above. The only modification is the frequency sequence. Instead of the frequency sequence “0,1,2,3,1,2”, the two distinguishable channels are used. “Channel 1” is used for every ping with a “0,1,0,1,1” speed sequence and “channel 3” is used for every ping with a “1,1,1,0,0” speed sequence. Figure 42 shows the Frequency Division TH-CDMA modification and the parameters used with this design in a bucket. The modified files for Frequency Division and TH-CDMA are *sl1.c* and *sl2.c*.

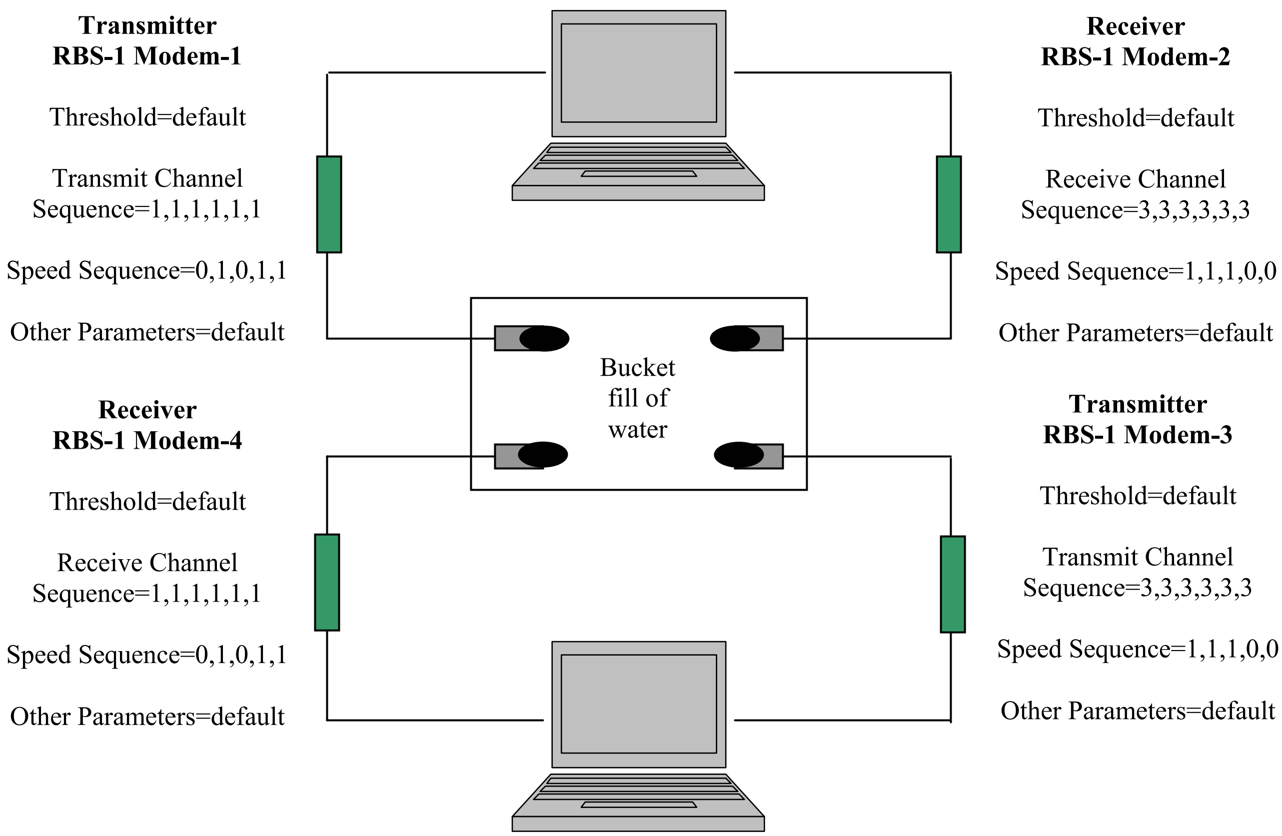

Figure 42. Frequency Division TH-CDMA Design and Parameters in a Bucket

4. AModem FH-CDMA Modification

FH-CDMA implementation with current RBS-1 modem requires hardware modification because of the frequency multiplication of the modulated signal and the Frequency Synthesizer signal. For test purposes, we will discuss the software modification that potentially could meet FH-CDMA requirements.

The original AModem code already has Frequency-Hopping implemented. The purpose of this implementation is multipath fading, as mentioned earlier. The original code frequency hopping is also not random.

FH-CDMA is the most likely one of all the CDMA modifications for successful full-duplex communication because of the four hopping channels. The only distinguishable channels are “channel 1” and “channel 3,” as mentioned earlier. Therefore, “channel 2” and “channel 0” hops would not be detected properly by the different receivers.

Normally, the frequency hops are determined by the chip sequence. For test purposes, the random selected frequency-hop implementation is tested in the next chapter. Two of the modems use a “1,2,0,2,2,0” frequency hop sequence and the other two used a “3,0,2,0,0,2” frequency hop sequence. Only the designated transmitter and receiver know the random series of frequencies used to transmit the data. Figure 43 shows the full duplex communication design with the FH-CDMA and the proper threshold and speed parameters in a bucket. The only modified file for FH-CDMA is *sl1.c*.

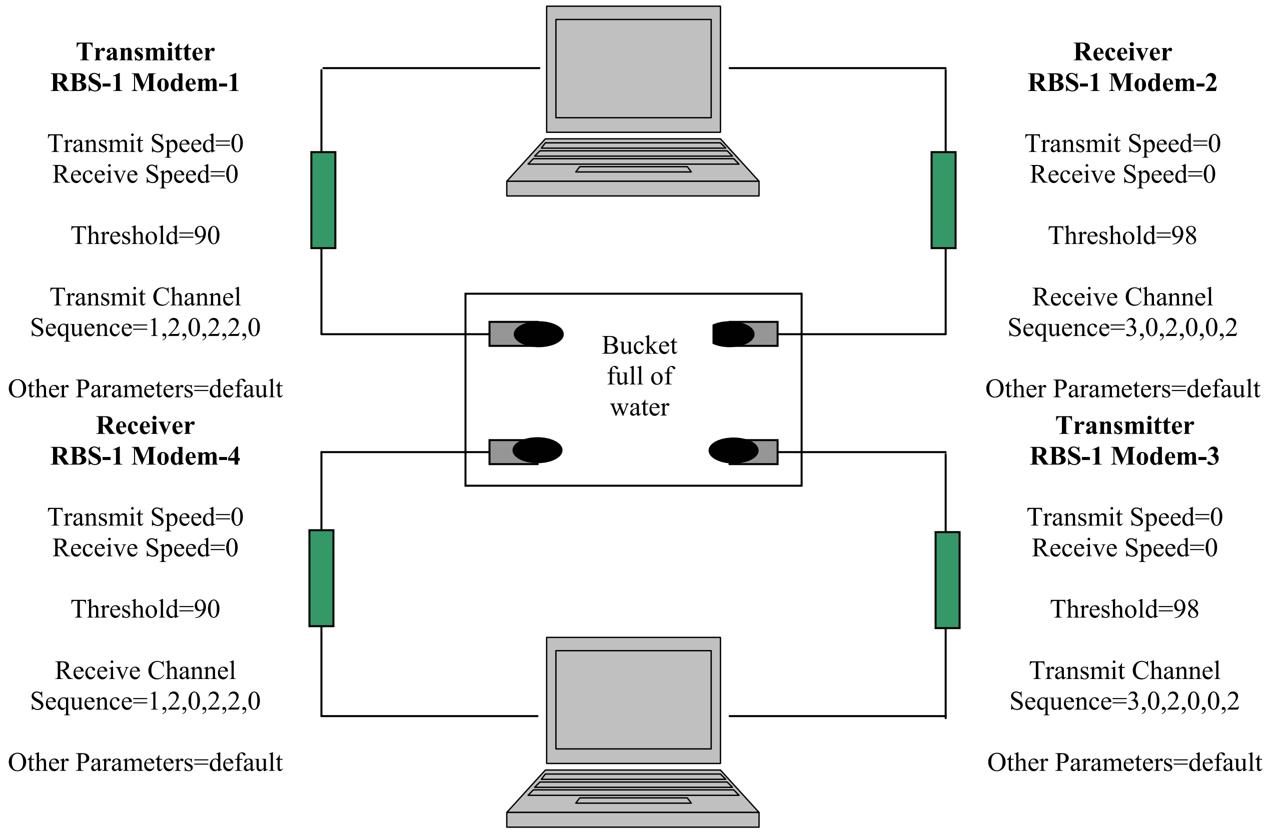

Figure 43. FH-CDMA Modification Design and Parameters in a Bucket

a. Frequency Division and FH-CDMA

This is the combination of Frequency Division Modification and FH-CDMA Modification. Once a better performance is secured with the Frequency Division, the combination with FH-CDMA is worth investigating.

The original AModem code has four different channels implemented and two of them are distinguishable, as mentioned earlier. Therefore, two of the modems are modified to use the randomly selected "channel 1"s and "channel 0"s sequence for all pings and the other two are modified to use the randomly selected "channel 3" and "channel 2" sequence for all pings. It is crucial to keep in mind that one must start the random sequences with two distinct frequencies in order to start the data transmission without doubt of error. Therefore, one sequence should start with "channel 1" and the other sequence should start with "channel 3."

The two randomly selected frequency sequences for this modification are "1,0,1,1,0,0" and "3,2,2,3,3,2". Two of the modems are modified to uses a "1,0,1,1,0,0" frequency sequence. The other two modems are modified to use a "3,2,2,3,3,2" frequency sequence for transmission.

Figure 44 shows the Frequency Division FH-CDMA modification and the parameters used with this design in a bucket. The only modified file for Frequency Division FH-CDMA is *sl1.c*.

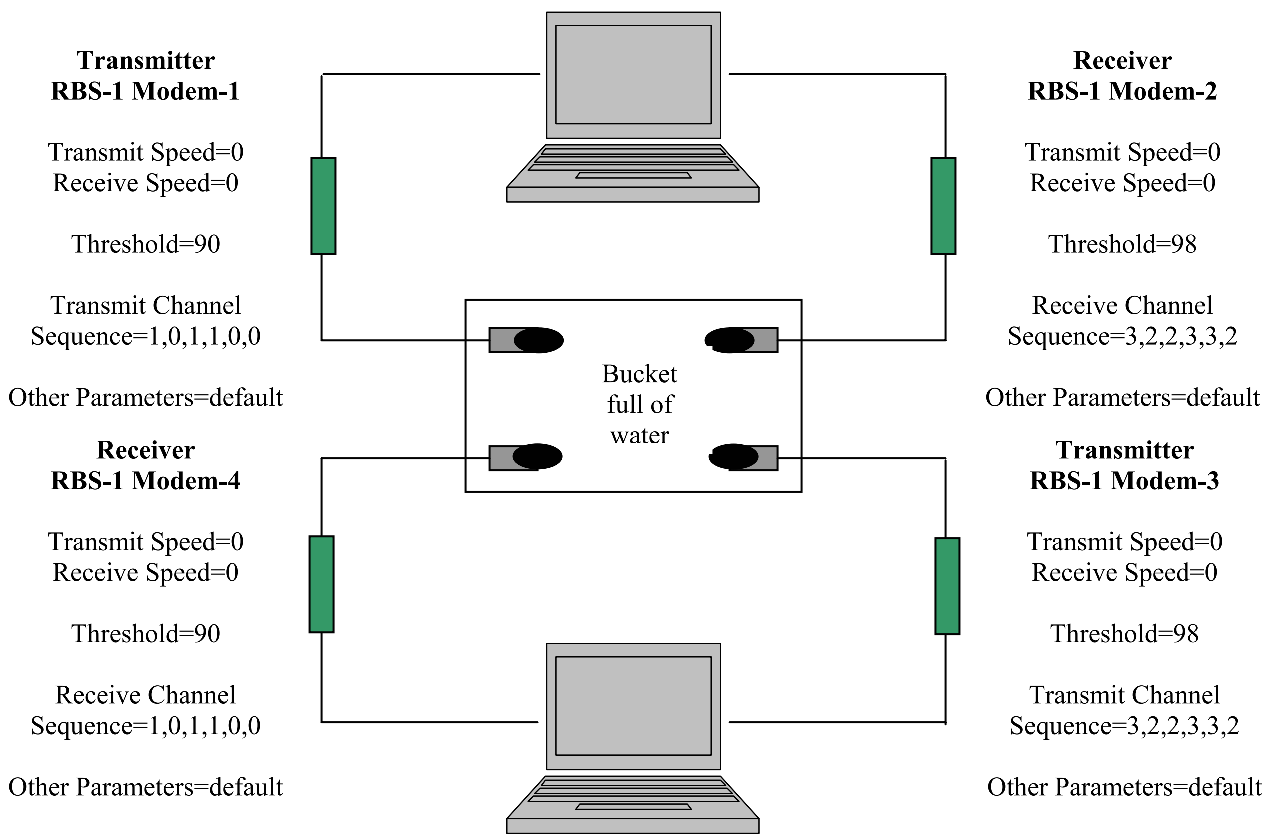

Figure 44. Frequency Division FH-CDMA Design and Parameters in a Bucket

5. AModem Hybrid (DS-TH)-CDMA Modification

This is the combination of DS-CDMA and TH-CDMA Modifications. Both Direct Sequence and Time-Hopping modifications applied to this modification.

Two of the modems use a "0,1,0,1,1" time-hopping sequence with the chip sequence "1,0,1,0" and the other two use a "1,1,1,0,0" time-hopping sequence with the chip sequence "1,1,1,1". Therefore the first pair of modems use a "1,0,1,0" chip sequence and speed 0 parameters between the first ping and the second ping, speed 1 parameters between the second ping and the third ping, speed 0 parameters between the third and the fourth ping, speed 1 parameters between the fourth and the fifth ping and speed 1 parameters between the fifth and the sixth ping. Likewise the second pair use a "1,1,1,1" chip sequence and speed 1 parameters between the first ping and the second ping, speed 1 parameters between the second ping and the third ping, speed 1 parameters between the third and the fourth ping, speed 0 parameters between the fourth and the fifth ping and speed 0 parameters between the fifth and the sixth ping. Only the transmitter and the receiver know the random series of chips and time hops used to transmit their data. Figure 45 shows the full-duplex communication design with the Hybrid CDMA and proper parameters in a bucket. The modified files for Hybrid CDMA are *amodem.c*, *sl1.c* and *sl2.c*.

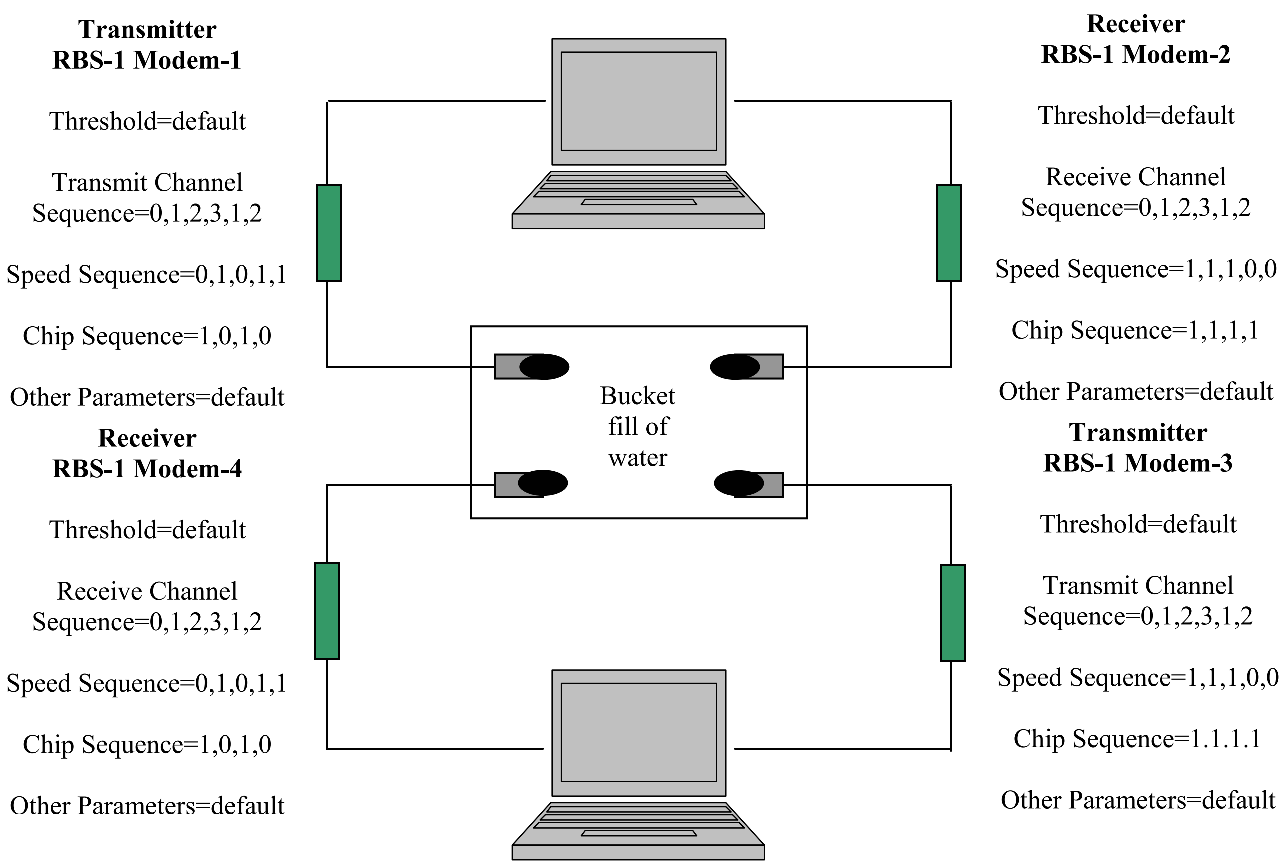

Figure 45. Hybrid-CDMA Modification Design and Parameters in a Bucket

The Hybrid CDMA Modification test procedure and the results will be discussed in the next chapter.

a. Frequency Division and DS-TH-CDMA

This is the combination of Frequency Division Modification and Hybrid CDMA Modification. Once getting the better performance with Frequency Division, the combination with FH-CDMA is worth a try.

The design is almost the same as the Hybrid-CDMA figure explained above. The only change is the frequency sequence. Instead of the frequency sequence "0,1,2,3,1,2", the two distinguishable channels are used. "Channel 1" is used for all pings with a "0,1,0,1,1" speed sequence and a "1,0,1,0" chip sequence, and likewise the "channel 3" is used for all pings with a "1,1,1,0,0" speed sequence and a "1,1,1,1" chip sequence. Figure 46 shows the Frequency Division TH-CDMA modification and the parameters used with this design in a bucket. The modified files for Frequency Division and TH-CDMA are *amodem.c*, *sl1.c* and *sl2.c*.

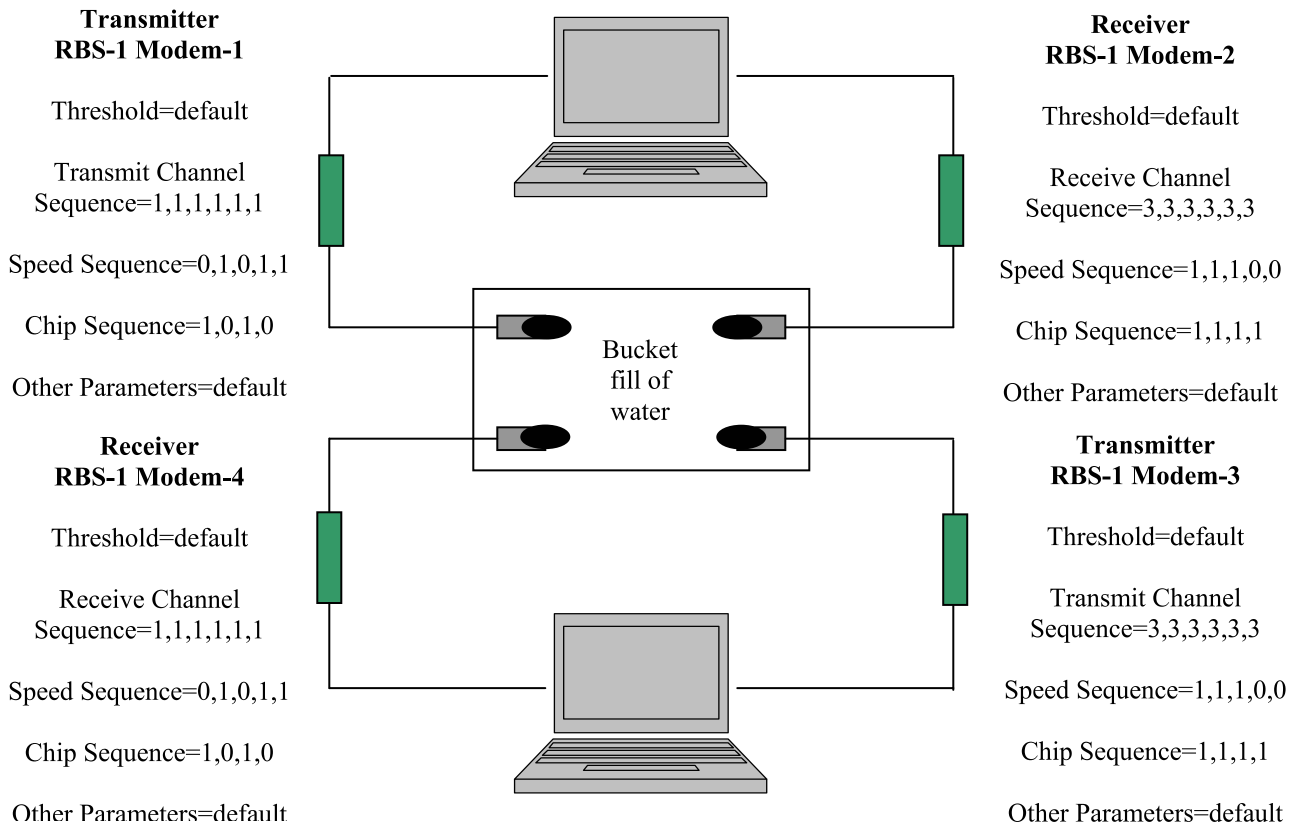

Figure 46. Frequency Division Hybrid-CDMA Design and Parameters in a Bucket

D. SUMMARY

This chapter discussed the CDMA techniques and the modification of the AModem software regarding to these methods. The FH-CDMA technique is the most likely one to establish a successful full-duplex communication.

The test procedures and the results, and the conclusions of these tests regarding to AModem CDMA modifications will be discussed in the next chapter.

V. TEST RESULTS

Several different test schemes were instituted while conducting this research. The tests are conducted in two different environments. The first test environment was a 20 X 14” bucket in the Network Lab (Spanagel Hall Room 238) and the second one was the Frog Pond in Del Rey Oaks.

During the Frog Pond test, the transducers from modems one and two were placed in the water on one side of the dock with the units spaced approximately one foot apart. Following the placement of the transducers one and two, transducers from modems three and four were placed in the water on the opposing side of the dock. The two sets of transducers were spaced 15 feet apart and all four transducers were inserted two inches in the water. Figure 47 illustrates this layout.

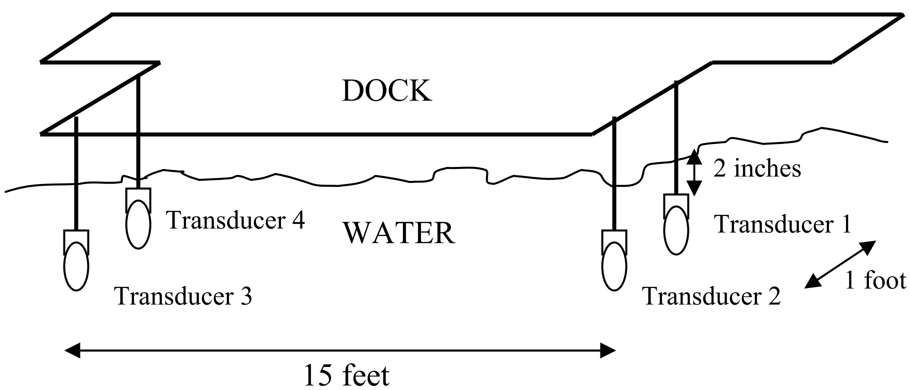

Figure 47. Lake Test Layout

The first part of each test verified that the modems were operational and only the designated receivers received the data. After verifying that the modems worked properly, each modem pair was tested individually with all four test sequences. Then a simultaneous transmission from modem 1 and modem 3 was tested for each of the CDMA modifications.

The following sections discuss the tests and the results of each, according to the modifications.

The test sequences used during the lake and bucket experiments are shown in Table 11.

Test Sequence 1	1234567890
Test Sequence 2	qwertyuiopasdfghjklzxcvbnm
Test Sequence 3	QWERTYUIOPASDFGHJKLZXCVBNM
Test Sequence 4	This is a test sentence.
Test Sequence 5	aaaassssddddffffgggghjhjhj
Test Sequence 6	zzzzxxxxccccvvvvbbbbnmnmnm
Test Sequence 7	qqqqqqqqqq

Table 11. Test Data Sequences

In the tables below, the "β" character represents blanks and the character "¥" represents one of the ASCII code. In each of these tests, blanks are not the same thing as "none!". The *Success Rate* is the ratio of the number of the characters received correctly by the receiver, over the number of characters transmitted from the transmitter or from both of the transmitters. The first goal is to achieve higher success rate for the designated receiver and 0% success rate for the other receiver. The second goal is to achieve simultaneous transmission.

A. AMODEM FREQUENCY-DIVISION MODIFICATION TEST

1. Bucket Test

TRANSMIT FROM MODEM 1

(MODEM 3 IS SILENT)

Test Sequence	Received by Modem 4	Success Rate
1	1234567890	100%
2	qwertyuiopasdfghjklzxcvbnm	100%
3	QWERTYUIOPASDFGHJKLZXCVBNM	100%
4	This is a test sentence	100%

Test Sequence	Received by Modem 2	Success Rate
1	None	0%
2	None	0%
3	None	0%
4	None	0%

TRANSMIT FROM MODEM 3

(MODEM 1 IS SILENT)

Test Sequence	Received by Modem 2	Success Rate
1	1234567890	100%
2	qwertyuiopasdfghjklzxcvbnm	100%
3	QWERTYUIOPASDFGHJKLZXCVBNM	100%
4	This is a test sentence	100%

Test Sequence	Received by Modem 4	Success Rate
1	None	0%
2	None	0%
3	None	0%
4	None	0%

SIMULTANEOUS TRANSMISSION TEST

Transmitted from Modem 1	Transmitted from Modem 3	Received by Modem 4	Received by Modem 2	Total Success Rate
5	6	aaββ ssss ddββ ffββ gggg ββhjhj	zzzz xxxx cccc vvvv bbbb nmnmnm	84.62%
6	5	zzzz ββxx ββββ vvvv ββbb nmnmnm	aaaa ssss dddd ffff gggg hjhjhj	84.62%
1	7	ββ34567890	qqqqqqqqqq	90%
7	1	qqqqqqqqqq	1234567890	100%

The first part of the test shows the designated receiver gets its designated transmitter's data without an error, while the other receiver gets none of the data. The second part of this test means the simultaneous transmission is achieved with frequency division in the bucket even though there are still a few errors. The first and the second line of the simultaneous transmission table have the same percentage of error. Additionally, the last line of the simultaneous transmission table gives a perfect full-duplex transmission example.

2. Lake Test

TRANSMIT FROM MODEM 1

(MODEM 3 IS SILENT)

Test Sequence	Received by Modem 4	Success Rate
1	1234567890	100%
2	qwertyuiopasdfghjklzxcvbnm	100%
3	QWERTYUIOPASDFGHJKLZXCVBNM	100%
4	This is a test sentence	100%

Test Sequence	Received by Modem 2	Success Rate
1	None	0%
2	None	0%
3	None	0%
4	None	0%

TRANSMIT FROM MODEM 3

(MODEM 1 IS SILENT)

Test Sequence	Received by Modem 2	Success Rate
1	1234567890	100%
2	qwertyuiopasdfghjklzxcvbnm	100%
3	QWERTYUIOPASDFGHJKLZXCVBNM	100%
4	This is a test sentence	100%

Test Sequence	Received by Modem 4	Success Rate
1	None	0%
2	None	0%
3	None	0%
4	None	0%

SIMULTANEOUS TRANSMISSION TEST

Transmitted from Modem 1	Transmitted from Modem 3	Received by Modem 4	Received by Modem 2	Total Success Rate
5	6	aaaa ssss dddd ffββ gggg hjhjhj	zzzz xxxx ccββ vvvv bbbb nmnmββ	92.31%
6	5	zzzz xxxx ccccc vvvv bbbb nmnmnm	ββaa ssss dddd ffff ggββ hjhjhj	92.31%
1	7	1234567890	qqqqqqqqqq	100%
7	1	qqqqqqqqqq	1234567890	100%

The first part of the test shows that the designated receiver gets its designated transmitter's data without an error while the other receiver gets none of the data. The second part of this test means that the simultaneous transmission is achieved with frequency division in the lake even though there are still a few errors. As the tables show, the lake test results are a little better than the bucket test according to the total success rate, since the lake is not a high-echo environment.

B. AMODEM DS-CDMA MODIFICATION TEST

1. Bucket Test

TRANSMIT FROM MODEM 1

(MODEM 3 IS SILENT)

Test Sequence	Received by Modem 4	Success Rate
1	1234567890	100%
2	qwertyuiopasdfghjklzxcvbnm	100%
3	QWERTYUIOPASDFGHJKLZXCVBNM	100%
4	This is a test sentence	100%

Test Sequence	Received by Modem 2	Success Rate
1	None	0%
2	None	0%
3	None	0%
4	None	0%

TRANSMIT FROM MODEM 3

(MODEM 1 IS SILENT)

Test Sequence	Received by Modem 2	Success Rate
1	1234567890	100%
2	qwertyuiopasdfghjklzxcvbnm	100%
3	QWERTYUIOPASDFGHJKLZXCVBNM	100%
4	This is a test sentence	100%

Test Sequence	Received by Modem 4	Success Rate
1	None	0%
2	None	0%
3	None	0%
4	None	0%

SIMULTANEOUS TRANSMISSION TEST

Transmitted from Modem 1	Transmitted from Modem 3	Received by Modem 4	Received by Modem 2	Total Success Rate
5	6	None	ββββ ¥¥¥¥ ββββ ββββ ββββ ββββββ	0%
6	5	None	ββββ ββββ ββββ ββββ ββββ ββββββ	0%
1	7	None	ββββββββββ	0%
7	1	¥β¥ββ¥	βββ¥βββ¥β	0%

The first part of the test shows the designated receiver gets its designated transmitter's data without an error while the other receiver gets none of the data. The second part of this test shows that the simultaneous transmission is not achieved with DS-CDMA modification in the bucket due to numerous errors. As you can see from the table above, modem 4 is not getting any of the data − except the last line − while transmitter modem 3 is transmitting. The reception of the modem 4 shown in the last line is probably after modem 3 stops its transmission.

2. Lake Test

TRANSMIT FROM MODEM 1

(MODEM 3 IS SILENT)

Test Sequence	Received by Modem 4	Success Rate
1	1234567890	100%
2	qwertyuiopasdfghjklzxcvbnm	100%
3	QWERTYUIOPASDFGHJKLZXCVBNM	100%
4	This is a test sentence	100%

Test Sequence	Received by Modem 2	Success Rate
1	None	0%
2	None	0%
3	None	0%
4	None	0%

TRANSMIT FROM MODEM 3

(MODEM 1 IS SILENT)

Test Sequence	Received by Modem 2	Success Rate
1	1234567890	100%
2	qwertyuiopasdfghjklzxcvbnm	100%
3	QWERTYUIOPASDFGHJKLZXCVBNM	100%
4	This is a test sentence	100%

Test Sequence	Received by Modem 4	Success Rate
1	None	0%
2	None	0%
3	None	0%
4	None	0%

SIMULTANEOUS TRANSMISSION TEST

Transmitted from Modem 1	Transmitted from Modem 3	Received by Modem 4	Received by Modem 2	Total Success Rate
5	6	¥¥ββ β¥ββ ββββ ¥¥¥¥ fff¥ ¥¥¥¥¥¥¥¥	¥¥¥¥ ββββ ¥¥¥¥ ββββ ¥¥¥¥ ββ¥¥nm	9.62%
6	5	None	ββββ ββββ ββββ ββββ ββββ ββββββ	0%
1	7	None	ββββ¥βββββ	0%
7	1	ββ¥ββββββ	βββββββββ ββββ	0%

The first part of the test shows the designated receiver gets its designated transmitter's data without an error while the other receiver gets none of the data. The second part of this test shows the simultaneous transmission is not achieved with DS-CDMA modification in the lake since there are a lot of errors. As the tables above illustrate, the lake DS-CDMA test results are better than bucket test results.

C. AMODEM DS-CDMA WITH FREQUENCY DIVISION MODIFICATION TEST

1. Bucket Test

TRANSMIT FROM MODEM 1

(MODEM 3 IS SILENT)

Test Sequence	Received by Modem 4	Success Rate
1	12345¥7¥90	80%
2	qwertyuiopasdfghjklzxcvbnm	100%
3	QWERTYUIOPASDFGHJKLZXCVBNM	100%
4	This is a test sentence	100%

Test Sequence	Received by Modem 2	Success Rate
1	None	0%
2	None	0%
3	None	0%
4	None	0%

TRANSMIT FROM MODEM 3

(MODEM 1 IS SILENT)

Test Sequence	**Received by Modem 2**	**Success Rate**
1	1234567890	100%
2	qwertyuiopasdfghjklzxcvbnm	100%
3	QWERTYUIOPASDFGHJKLZXCVBNM	100%
4	This is a test sentence	100%

Test Sequence	**Received by Modem 4**	**Success Rate**
1	None	0%
2	None	0%
3	None	0%
4	None	0%

SIMULTANEOUS TRANSMISSION TEST

Transmitted from Modem 1	**Transmitted from Modem 3**	**Received by Modem 4**	**Received by Modem 2**	**Total Success Rate**
5	6	aaaa ss¥¥ d¥¥d ¥¥¥f g¥gg ¥j¥¥	¥zzz xxxx cccc vvvv bbbb nmnmnm	71.15%
6	5	z¥ ¥x¥x ¥¥cc ¥v¥¥ ¥¥b¥ ¥¥nm¥	aaaa ¥¥¥s d¥¥¥ ¥¥ff ggg¥ hjhjhj	50%
1	7	1¥3¥567¥9	¥qq¥¥qq¥qq	60%
7	1	¥qββ¥q¥qq¥	123¥56¥890	55%

The first part of the test reveals that the designated receiver gets its designated transmitter's data without an error while the other receiver gets none of the data. The second part of this test implies the simultaneous transmission is achieved with frequency division DS-CDMA in the bucket even with still remaining a few errors. However, in this case, the channels are physically divided.

2. Lake Test

TRANSMIT FROM MODEM 1

(MODEM 3 IS SILENT)

Test Sequence	Received by Modem 4	Success Rate
1	1234567890	100%
2	qwertyuiopasdfghjklzxcvbnm	100%
3	QWERTYUIOPASDFGHJKLZXCVBNM	100%
4	This is a test sentence	100%

Test Sequence	Received by Modem 2	Success Rate
1	None	0%
2	None	0%
3	None	0%
4	None	0%

TRANSMIT FROM MODEM 3

(MODEM 1 IS SILENT)

Test Sequence	Received by Modem 2	Success Rate
1	1234567890	100%
2	qwertyuiopasdfghjklzxcvbnm	100%
3	QWERTYUIOPASDFGHJKLZXCVBNM	100%
4	This is a test sentence	100%

Test Sequence	Received by Modem 4	Success Rate
1	None	0%
2	None	0%
3	None	0%
4	None	0%

SIMULTANEOUS TRANSMISSION TEST

Transmitted from Modem 1	Transmitted from Modem 3	Received by Modem 4	Received by Modem 2	Total Success Rate
5	6	aaaa ssss dddd ffff gggg hjhjhj	zzzz xxxx cccc vvvv bbbb nmnmnm	100%
6	5	zzzz xxxx cccc vvvv bbbb nmnmnm	~~¥¥¥¥~~ ~~¥¥¥¥~~ ~~¥¥¥¥~~ ffff ~~¥¥¥¥~~ ~~¥¥¥¥¥¥~~	57.69%
1	7	1234567890	qqqqqqqqqq	100%
7	1	qqqqqqqqqq	1234~~¥¥¥¥¥¥~~	70%

The first part of the test shows the designated receiver gets its designated transmitter's data without an error while the other receiver gets none of the data. The second part of this test implies that the simultaneous transmission is achieved with frequency division DS-CDMA in the lake even though there are still a few errors. The results are better than the bucket test results. However, the channels are physically divided in this case.

D. AMODEM TH-CDMA MODIFICATION TEST

1. Bucket Test

TRANSMIT FROM MODEM 1

(MODEM 3 IS SILENT)

Test Sequence	Received by Modem 4	Success Rate
1	1234567890	100%
2	qwertyuiopasdfghjklzxcvbnm	100%
3	QWERTYUIOPASDFGHJKLZXCVBNM	100%
4	This is a test sentence	100%

Test Sequence	Received by Modem 2	Success Rate
1	None	0%
2	ββββ	0%
3	ββββ	0%
4	ββββββ	0%

Modem 2 is the designated receiver for the modem 3 transmitter. Even though modem 3 is silent for this part of the test, modem 2 gets blanks during the TH-CDMA modification test.

TRANSMIT FROM MODEM 3

(MODEM 1 IS SILENT)

Test Sequence	Received by Modem 2	Success Rate
1	1234567890	100%
2	qwertyuiopasdfghjklzxcvbββ	92.31%
3	QWERTYUIOPASDFGHJKLZXCVBββ	92.31%
4	This is a test sentence	100%

Test Sequence	Received by Modem 4	Success Rate
1	None	0%
2	None	0%
3	None	0%
4	ββ	0%

Modem 4 is the designated receiver for the modem 1 transmitter. Even though modem 1 is silent for this part of the test, modem 4 gets blanks during the TH-CDMA modification test.

SIMULTANEOUS TRANSMISSION TEST

Transmitted from Modem 1	Transmitted from Modem 3	Received by Modem 4	Received by Modem 2	Total Success Rate
5	6	ββββ ββββ ¥¥ββ ββββ ββββ ββhjhj	ββββ ββββ ccββ ββββ ββββ ¥¥ββββ	11.54%
6	5	ββββ ββββ ββββ ββββ ββββ ββnmnm	ββββ ββββ ββdd ββββ ββββ ββββββ	11.54%
1	7	ββββββββ90	ββββ¥¥ββββββ	10%
7	1	ββββββββqq	ββββββββββ	10%

The first part of the test implies the designated receiver gets its designated transmitter’s data without an error, while the other receiver gets a few blanks. The second part of this test means the simultaneous transmission is not achieved with TH-CDMA in the bucket since there are a lot of errors.

2. Lake Test

TRANSMIT FROM MODEM 1

(MODEM 3 IS SILENT)

Test Sequence	**Received by Modem 4**	**Success Rate**
1	1234567890	100%
2	qwertyuiopasdfghjklzxcvbnm	100%
3	QWERTYUIOPASDFGHJKLZXCVBNM	100%
4	This is a test sentence	100%

Test Sequence	**Received by Modem 2**	**Success Rate**
1	ββββββ	0%
2	ββββββ	0%
3	ββββββ	0%
4	ββββββ	0%

Modem 2 is the designated receiver for the modem 3 transmitter. Even though modem 3 is silent for this part of the test, modem 2 gets blanks during the TH-CDMA modification test.

TRANSMIT FROM MODEM 3

(MODEM 1 IS SILENT)

Test Sequence	**Received by Modem 2**	**Success Rate**
1	1234567890	100%
2	qwertyuiopasdfghjklzxcvbββ	92.31%
3	QWERTYUIOPASDFGHJKLZXCVBNM	100%
4	This is a test sentence	100%

Test Sequence	**Received by Modem 4**	**Success Rate**
1	ββββββββββ	0%
2	ββββββββββββββββββββββββββ	0%
3	ββββββββββββββββββββββββββ	0%
4	ββββββββββββββββββββββββ	0%

Modem 4 is the designated receiver for the modem 1 transmitter. Even though modem 1 is silent for this part of the test, modem 4 gets blanks during the TH-CDMA modification test.

SIMULTANEOUS TRANSMISSION TEST

Transmitted from Modem 1	**Transmitted from Modem 3**	**Received by Modem 4**	**Received by Modem 2**	**Total Success Rate**
5	6	ββββ ββββ ββββ ββββ ββββ ββhjhj	ββββ ββββ ββββ ββββ ββββ ββββββ	7.69%
6	5	ββββ ββββ ββββ ββββ ββββ nmnmββ	aaββ ββββ ββββ ββββ ββββ ββββββ	11.53%
1	7	¥ββ90	ββββββββββ	10%
7	1	ββββββββββ	ββ34βββ¥¥ββ	10%

The first part of the test shows that the designated receiver gets its designated transmitter's data without an error while the other receiver gets some blanks. The second part of this test means the simultaneous transmission is not achieved with TH-CDMA in the lake owing to numerous errors. As you can see from the simultaneous transmission table, simultaneous time hopping in the bucket obtains a lot of blank data. The reason for this might be because speed option 1 was employed in the high-echo environment even though it was not advised by Desert Star. Another critical finding is that the number of blank data is greater than in the bucket test. The Desert Star design has the modems insert blanks when it can not decipher the received character.

E. AMODEM TH-CDMA WITH FREQUENCY DIVISION MODIFICATION TEST

1. Bucket Test

TRANSMIT FROM MODEM 1

(MODEM 3 IS SILENT)

Test Sequence	Received by Modem 4	Success Rate
1	1234567890	100%
2	qwertyuiopasdfghjklzxcvbnm	100%
3	QWERTYUIOPASDFGHJKLZXCVBNM	100%
4	This is a test sentence	100%

Test Sequence	Received by Modem 2	Success Rate
1	None	0%
2	None	0%
3	None	0%
4	None	0%

TRANSMIT FROM MODEM 3

(MODEM 1 IS SILENT)

Test Sequence	Received by Modem 2	Success Rate
1	1234567890	100%
2	qwertyuiopasdfghjklzxcvbββ	92.31%
3	QWERTYUIOPASDFGHJKLZXCVBββ	92.31%
4	This is a test sentence	100%

Test Sequence	Received by Modem 4	Success Rate
1	None	0%
2	None	0%
3	None	0%
4	None	0%

SIMULTANEOUS TRANSMISSION TEST

Transmitted from Modem 1	Transmitted from Modem 3	Received by Modem 4	Received by Modem 2	Total Success Rate
5	6	aaββ ssss ββββ ffββ ββgg hjhjhj	zzzz xxββ ββββ vvββ bbbb nmnmββ	61.54%
6	5	zzββ ββββ ββcc ββββ ββbb ββnmnm	aaaa ssss dddd ffff gggg hjhjhj	69.23%
1	7	ββ34567890	qqqqqqqqqq	90%
7	1	qqqqqqqqqq	1234567890	100%

The first part of the test exhibits the designated receiver gets its designated transmitter's data without an error, while the other receiver gets none. The second part of this test means the simultaneous transmission is achieved with the frequency division TH-CDMA in the bucket even though there are still a few errors. However, in this case the channels are physically divided into two parts. The total success rates are higher than the frequency division DS-CDMA test in the bucket

2. Lake Test

TRANSMIT FROM MODEM 1

(MODEM 3 IS SILENT)

Test Sequence	Received by Modem 4	Success Rate
1	1234567890	100%
2	qwertyuiopasdfghjklzxcvbnm	100%
3	QWERTYUIOPASDFGHJKLZXCVBNM	100%
4	This is a test sentence	100%

Test Sequence	Received by Modem 2	Success Rate
1	None	0%
2	None	0%
3	None	0%
4	None	0%

TRANSMIT FROM MODEM 3

(MODEM 1 IS SILENT)

Test Sequence	Received by Modem 2	Success Rate
1	1234567890	100%
2	qwertyuiopasdfghjklzxcvbββ	92.31%
3	QWERTYUIOPASDFGHJKLZXCVBββ	92.31%
4	This is a test sentence	100%

Test Sequence	Received by Modem 4	Success Rate
1	None	0%
2	None	0%
3	None	0%
4	None	0%

SIMULTANEOUS TRANSMISSION TEST

Transmitted from Modem 1	Transmitted from Modem 3	Received by Modem 4	Received by Modem 2	Total Success Rate
5	6	aaββ ssss ββdd ffff gggg hjhjhj	ββββ xxxx ccββ vvvv bbbb ββββββ	69.23%
6	5	zzzz xxxx cccc vvvv bbbb ββnmnm	aaaa ssββ dddd ffff gggg hjhjββ	88.46%
1	7	1234ββ7890	βββββqqqqqq	70%
7	1	qqββqqqqqq	123456ββ90	80%

The first part of the test shows that the designated receiver gets its designated transmitter's data without an error, while other receiver gets none of it. The second part of this test implies that the simultaneous transmission is achieved with the frequency division TH-CDMA in the lake even though there are a few errors. The frequency divided TH-CDMA lake test results is better than the bucket test of this implementation.

F. AMODEM FH-CDMA MODIFICATION TEST

1. Bucket Test

TRANSMIT FROM MODEM 1

(MODEM 3 IS SILENT)

Test Sequence	Received by Modem 4	Success Rate
1	12ββ567890	80%
2	qwertyuiopasdfghjkββxcvbnm	92.31%
3	QWERTYUIOPASDFGHJKββXCVBββ	84.62%
4	This is a test sentence	100%

Test Sequence	Received by Modem 2	Success Rate
1	ββ	0%
2	ββββββββββββββ	0%
3	ββββββββββ	0%
4	ββββββββββββββ	0%

Modem 2 is the designated receiver for the modem 3 transmitter. Even though modem 3 is silent for this part of the test, modem 2 gets blanks during FH-CDMA modification test.

TRANSMIT FROM MODEM 3

(MODEM 1 IS SILENT)

Test Sequence	Received by Modem 2	Success Rate
1	1234567890	100%
2	qwertyuiopasdfghjklzxcvbββ	92.31%
3	QWERTYUIOPASDFGHJKLZXCββNM	92.31%
4	This is a test sentence	100%

Test Sequence	Received by Modem 4	Success Rate
1	None	0%
2	ββββββββββ	0%
3	ββββββββ	0%
4	ββββββββββββββ	0%

Modem 4 is the designated receiver for the modem 1 transmitter. Even though modem 1 is silent for this part of the test, modem 4 gets blanks during FH-CDMA modification test.

SIMULTANEOUS TRANSMISSION TEST

Transmitted from Modem 1	Transmitted from Modem 3	Received by Modem 4	Received by Modem 2	Total Success Rate
5	6	aaββ ssss dddd ffff ggββ ββββhj	zzzz xxxx cccc vvvv bbββ ββnmnm	76.92%
6	5	zzzz xxββ cccc ββββ bbbb nmnmnm	aaaa ssββ ββββ ffff ββββ hjhjhj	69.23%
1	7	1234567890	ββqqqqqqββ	80%
7	1	ββββqqqqqq	1234ββββββ	50%

The first part of the test shows the designated receiver gets its designated transmitter's data without an error, while the other receiver gets a number of blanks. The second part of this test means that the simultaneous transmission is achieved with FH-CDMA in the bucket even though there are still a few errors. As seen from the settings and modification of this implementation, only when the synchronization ping is physically divided can simultaneous transmission be achieved.

2. Lake Test

TRANSMIT FROM MODEM 1

(MODEM 3 IS SILENT)

Test Sequence	Received by Modem 4	Success Rate
1	1234567890	100%
2	qwertyuiopasdfghjklzxcvbnm	100%
3	QWERTYUIOPASDFGHJKLZXCVBNM	100%
4	This is a test sentence.	100%

Test Sequence	Received by Modem 2	Success Rate
1	ββββ	0%
2	ββββββββββββ	0%
3	ββββββββββββ	0%
4	ββββββββββββ	0%

Modem 2 is the designated receiver for the modem 3 transmitter. Even though modem 3 is silent for this part of the test, modem 2 gets blanks during FH-CDMA modification test.

TRANSMIT FROM MODEM 3

(MODEM 1 IS SILENT)

Test Sequence	Received by Modem 2	Success Rate
1	1234567890	100%
2	qwertyuiopasdfghjklzxcvbββ	100%
3	QWERTYUIOPASDFGHJKLZXCVBNM	100%
4	This is a test sentence.	100%

Test Sequence	Received by Modem 4	Success Rate
1	ββββ	0%
2	ββββββββββ	0%
3	ββββββββββ	0%
4	βββββββββββββββββββ	0%

Modem 4 is the designated receiver for the modem 1 transmitter. Even though modem 1 is silent for this part of the test, modem 4 gets blanks during FH-CDMA modification test.

SIMULTANEOUS TRANSMISSION TEST

Transmitted from Modem 1	Transmitted from Modem 3	Received by Modem 4	Received by Modem 2	Total Success Rate
5	6	aaaa ssss dddd ffff gggg hjhjhj	zzzz xxxx cccc vvvv bbbb nmnmnm	100%
6	5	zzzz xxββ ββββ vvvv bbbb nmnmββ	aaaa ssss dddd ffff gggg hjhjhj	84.62%
1	7	1234567890	qqqqqqqqqq	100%
7	1	qqqqqqqqqq	1234567890	100%

The first part of the test exhibits the designated receiver gets its designated transmitter's data without an error, while the other receiver gets some blanks. The second part of this test shows the simultaneous transmission is achieved with FH-CDMA in the lake even though there are still a few errors. This test result is the most successful one of all the tests.

G. AMODEM FH-CDMA WITH FREQUENCY DIVISION MODIFICATION TEST

1. Bucket Test

TRANSMIT FROM MODEM 1

(MODEM 3 IS SILENT)

Test Sequence	Received by Modem 4	Success Rate
1	1234567890	100%
2	qwertyuiopasdfghjklzxcvbnm	100%
3	QWERTYUIOPASDFGHJKLZXCVBNM	100%
4	This is a test sentence	100%

Test Sequence	Received by Modem 2	Success Rate
1	None	0%
2	None	0%
3	None	0%
4	None	0%

TRANSMIT FROM MODEM 3

(MODEM 1 IS SILENT)

Test Sequence	Received by Modem 2	Success Rate
1	1234567890	100%
2	qwertyuiopasdfghjklzxcvbnm	100%
3	QWERTYUIOPASDFGHJKLZXCVBNM	100%
4	This is a test sentence	100%

Test Sequence	Received by Modem 4	Success Rate
1	None	0%
2	None	0%
3	None	0%
4	None	0%

SIMULTANEOUS TRANSMISSION TEST

Transmitted from Modem 1	Transmitted from Modem 3	Received by Modem 4	Received by Modem 2	Total Success Rate
5	6	ββββ ββss dddd ffff gggg hjββββ	zzzz xxxx cccc vvvv ββbb ββnmnm	73.08%
6	5	zzzz xxxx cccc vvvv bbbb nmnmnm	aaaa ββββ dddd ffff gggg hjhjhj	92.31%
1	7	1234567890	qqββqqqqββ	80%
7	1	qqqqqqqqqq	1234567890	100%

The first part of the test shows the designated receiver gets its designated transmitter's data without an error, while the other receiver gets nothing. The second part of the test means the simultaneous transmission is achieved with the frequency division FH-CDMA in the bucket even with a few errors. However, the channel is physically divided in this case.

2. Lake Test

TRANSMIT FROM MODEM 1

(MODEM 3 IS SILENT)

Test Sequence	Received by Modem 4	Success Rate
1	1234567890	100%
2	qwertyuiopasdfghjklzxcvbnm	100%
3	QWERTYUIOPASDFGHJKLZXCVBNM	100%
4	This is a test sentence	100%

Test Sequence	Received by Modem 2	Success Rate
1	None	0%
2	None	0%
3	None	0%
4	None	0%

TRANSMIT FROM MODEM 3

(MODEM 1 IS SILENT)

Test Sequence	Received by Modem 2	Success Rate
1	1234567890	100%
2	qwertyuiopasdfghjklzxcvbnm	100%
3	QWERTYUIOPASDFGHJKLZXCVBNM	100%
4	This is a test sentence	100%

Test Sequence	Received by Modem 4	Success Rate
1	None	0%
2	None	0%
3	None	0%
4	None	0%

SIMULTANEOUS TRANSMISSION TEST

Transmitted from Modem 1	Transmitted from Modem 3	Received by Modem 4	Received by Modem 2	Total Success Rate
5	6	aaaa ssss dddd ffff ββββ hjhjhj	zzzz ββxx ββcc vvvv bbbb ββββββ	73.08%
6	5	ββββ xxxx cccc vvvv bbbb nmnmnm	aaaa ssss ddββ ββββ gggg hjhjββ	76.92%
1	7	1234ββββ90	qqββqqqqqq	70%
7	1	qqqqqqqqqq	ββ34567890	90%

The first part of the test implies the designated receiver gets its designated transmitter's data without an error, while the other receiver gets nothing. The second part of this test exhibits that simultaneous transmission is achieved with the frequency division FH-CDMA in the lake even though there are still a few errors. However, the channel is physically divided in this case. The simultaneous test results are worse than the bucket tests of this implementation.

H. AMODEM HYBRID (DS-TH)-CDMA MODIFICATION TEST

1. Bucket Test

TRANSMIT FROM MODEM 1

(MODEM 3 IS SILENT)

Test Sequence	Received by Modem 4	Success Rate
1	1234567890	100%
2	qwertyuiopasdfghjklzxcvbnm	100%
3	QWERTYUIOPASDFGHJKLZXCVBNM	100%
4	This is a test sentence	100%

Test Sequence	Received by Modem 2	Success Rate
1	None	0%
2	None	0%
3	None	0%
4	None	0%

TRANSMIT FROM MODEM 3

(MODEM 1 IS SILENT)

Test Sequence	**Received by Modem 2**	**Success Rate**
1	1234567890	100%
2	qwertyuiopasdfghjklzxcvbnm	100%
3	QWERTYUIOPASDFGHJKLZXCVBNM	100%
4	This is a test sentence	100%

Test Sequence	**Received by Modem 4**	**Success Rate**
1	None	0%
2	None	0%
3	None	0%
4	None	0%

SIMULTANEOUS TRANSMISSION TEST

Transmitted from Modem 1	**Transmitted from Modem 3**	**Received by Modem 4**	**Received by Modem 2**	**Total Success Rate**
5	6	ββββ ββββ ββββ ββββ ββββ ββ¥¥¥¥	ββββ ¥β¥β ββββ ββββ ββββ ¥¥ββββ	0%
6	5	ββββ ββββ ββββ ββββ ββββ ββ¥¥¥¥	Bββ¥ ββ¥β ¥βββ ββββ ββββ ββ¥¥¥¥	0%
1	7	¥βββ¥ββββ¥	ββββ¥βββ	0%
7	1	ββββββββ¥q	¥βββ¥ββ¥¥	0%

The first part of the test shows the designated receiver gets its designated transmitter's data without an error, while the other receiver gets nothing. The second part of this test implies that the simultaneous transmission is not achieved with HYBRID-CDMA in the bucket, since there are numerous errors. The simultaneous test results are worse than the TH-CDMA and DS-CDMA since this implementation is a combination of both.

2. Lake Test

TRANSMIT FROM MODEM 1

(MODEM 3 IS SILENT)

Test Sequence	Received by Modem 4	Success Rate
1	1234567890	96.15%
2	qwertyui¥pasdfghjklzxcvbnm	100%
3	QWERTYUIOPASDFGHJKLZXCVBNM	100%
4	This is a test sentence	100%

Test Sequence	Received by Modem 2	Success Rate
1	ββββββββββ	0%
2	ββββββββββ¥β¥ββββββββββββββ	0%
3	ββββββββββββββββββββββββββ	0%
4	¥βββββββββββ¥ββ¥β¥βββ¥ββ	0%

Modem 2 is the designated receiver for the modem 3 transmitter. Even though modem 3 is silent for this part of the test, modem 2 gets blanks during FH-CDMA modification test.

TRANSMIT FROM MODEM 3

(MODEM 1 IS SILENT)

Test Sequence	Received by Modem 2	Success Rate
1	1234567890	100%
2	qwertyuiopasdfghjklzxcvbnm	100%
3	QWERTYUIOPASDFGHJKLZXCVBNM	100%
4	This is a test sentence	100%

Test Sequence	Received by Modem 4	Success Rate
1	None	0%
2	None	0%
3	None	0%
4	None	0%

SIMULTANEOUS TRANSMISSION TEST

Transmitted from Modem 1	Transmitted from Modem 3	Received by Modem 4	Received by Modem 2	Total Success Rate
5	6	hj	βββ¥ β¥¥β β¥ββ βββ¥ ββββ βββ¥ββ	3.85%
6	5	βββββββββββ βββ¥nmnm	ββββ β¥β¥ ββββ ββββ β¥ββ ββββββ	7.69%
1	7	β¥βββββ¥9	¥ββ¥β¥βββ	0%
7	1	ββββββq	¥βββ¥ββ¥¥	5%

The first part of the test shows the designated receiver gets its designated transmitter's data without an error, while other receiver gets nothing. The second part of this test implies that the simultaneous transmission is not achieved with the HYBRID-CDMA in the lake since there are many errors. However, the results are better than the bucket test results of this implementation.

I. AMODEM HYBRID (DS-TH) CDMA WITH FREQUENCY DIVISION MODIFICATION TEST

1. Bucket Test

TRANSMIT FROM MODEM 1

(MODEM 3 IS SILENT)

Test Sequence	Received by Modem 4	Success Rate
1	1234567890	100%
2	qwertyuiopasdfghjklzxcvbnm	100%
3	QWERTYUIOPASDFGHJKLZXCVBNM	100%
4	This is a test sentence	100%

Test Sequence	Received by Modem 2	Success Rate
1	None	0%
2	None	0%
3	None	0%
4	None	0%

TRANSMIT FROM MODEM 3

(MODEM 1 IS SILENT)

Test Sequence	Received by Modem 2	Success Rate
1	1234567890	100%
2	qwertyuiopasdfghjklzxcvbnm	100%
3	QWERTYUIOPASDFGHJKLZXCVBNM	100%
4	This is a test sentence	100%

Test Sequence	Received by Modem 4	Success Rate
1	None	0%
2	None	0%
3	None	0%
4	None	0%

SIMULTANEOUS TRANSMISSION TEST

Transmitted from Modem 1	Transmitted from Modem 3	Received by Modem 4	Received by Modem 2	Total Success Rate
5	6	β¥aa ¥sss dddd fff¥ ¥gg¥ hjhjhj	zzzz ¥xxx ¥¥cc vv¥βv bbbb nm¥¥¥¥	73.08%
6	5	zzzz x¥¥x ¥¥cc ββv¥ ¥¥b¥ ¥mnmnm	¥¥¥¥ ¥¥¥¥ ffff ¥¥¥¥ ¥¥¥¥ ββ¥¥¥¥	36.53%
1	7	¥234567¥90	¥¥¥¥¥¥¥¥¥¥	40%
7	1	¥¥¥¥¥¥q¥qq	¥¥¥¥¥¥¥¥¥¥	15%

The first part of the test implies the designated receiver gets its designated transmitter’s data without an error, while the other receiver gets nothing. The second part of this test exhibits that the simultaneous transmission is not achieved with the frequency division HYBRID-CDMA in the bucket owing to numerous errors. Even though the channels are physically divided, the results were not successful, unlike the other frequency division CDMA tests

2. Lake Test

TRANSMIT FROM MODEM 1

(MODEM 3 IS SILENT)

Test Sequence	Received by Modem 4	Success Rate
1	1234567890	96.15%
2	qwertyui¥pasdfghjklzxcvbnm	100%
3	QWERTYUIOPASDFGHJKLZXCVBNM	100%
4	This is a test sentence	100%

Test Sequence	Received by Modem 2	Success Rate
1	None	0%
2	None	0%
3	None	0%
4	None	0%

TRANSMIT FROM MODEM 3

(MODEM 1 IS SILENT)

Test Sequence	Received by Modem 2	Success Rate
1	1234567890	100%
2	qwertyuiopasdfghjklzxcvbnm	100%
3	QWERTYUIOPASDFGHJKLZXCVBNM	100%
4	This is a test sentence	100%

Test Sequence	Received by Modem 4	Success Rate
1	None	0%
2	None	0%
3	None	0%
4	None	0%

SIMULTANEOUS TRANSMISSION TEST

Transmitted from Modem 1	Transmitted from Modem 3	Received by Modem 4	Received by Modem 2	Total Success Rate
5	6	a¥aa sss¥ ¥ddd ffff gg¥¥g ¥jhjhj	zz¥z xxxx cccc ¥¥¥f ¥¥¥¥ ¥¥¥¥¥¥	61.54%
6	5	zzz¥ ¥xxx cccc vvv¥ bb¥b nmnmnm	aaaa ssss dd¥d ff¥f ¥¥¥¥ ¥¥¥¥¥¥	69.23%
1	7	¥2¥45¥7890	¥¥¥¥¥¥¥¥¥¥	35%
7	1	qq¥qq¥¥qqq	¥¥¥¥¥¥¥¥¥¥¥	35%

The first part of the test exhibits the designated receiver gets its designated transmitter’s data without an error, while the other receiver gets nothing. The second part of this test implies the simultaneous transmission is not achieved with the frequency division HYBRID-CDMA in the lake because there are a lot of errors. However, the results were better than the bucket test results.

VI. CONCLUSIONS AND RECOMMENDATIONS

The primary thrust of this thesis was to develop a CDMA system for full-duplex underwater acoustic communication using four commercial Desert Star RBS-1 modems. Several conclusions and recommendations can be drawn from this thesis.

A. CONCLUSION

After several tests in the bucket and the lake with the four Desert Star RBS-1 acoustic modems, the results indicate that bandwidth-efficient full-duplex communication is feasible in underwater acoustic networks using CDMA techniques. In particular, the FH-CDMA method performs extremely well.

The major problem using the Desert Star modems to achieve full-duplex communication using CDMA was the lack of data source identification. As discussed in Chapter III, a synchronization ping is used to indicate the beginning of a 2-byte message block. In the original RBS-1 modem software implementation, a fixed frequency channel (channel 0) is used to transmit the synchronization pings. As a result, a receiving modem would not be able to distinguish synchronization pings from different transmitter modems. This thesis resolves the problem by revising the modem software so that different ping channels can be assigned to different modems. For example, in the FH-CDMA tests, the two transmitter modems use different frequency channels, Channel 1 and Channel 3, respectively, for synchronization pings, while using the same set of frequency channels (Channel 0 and Channel 2) for data pings.

This thesis also shows it is possible to achieve full-duplex underwater acoustic communication using FDMA techniques. However, FDMA techniques are not as bandwidth-efficient as CDMA techniques. The total underwater acoustic bandwidth is typically limited to several kHz, which imposes a very low data transfer rate unlike the wireless air communications. Therefore, the protocol must use the available transmission bandwidth as efficiently as possible. Since acoustic signals only travel at the speed of sound in water (approximately 1500 meter per second), a message may take several seconds to travel between two nodes. Thus, an error correction protocol or acknowledgement messages on top of FDMA would make the communication very slow. FDMA systems also do not handle frequency select fading well.

B. RECOMMENDATION

There are two major areas for future work. First, additional tests should actually be conducted in an ocean or sea. The noise, temperature, salinity and depth/pressure relationship in the ocean are different from the bucket or lake. The shallow water acoustic environment is challenging and more variable than might be predicted intuitively. As mentioned earlier in Chapter II, the noise from the sea surface is the primary challenge for RBS-1 modems. The new tests should include changing the receiver gain and the threshold settings to best match the ocean condition.

Second, the Desert Star RBS-1 modems have a very limited hardware capability. For example, they primarily use the time-domain to encode data, as discussed in Chapter III. However, FH-CDMA and DS-CDMA concern frequency-domain techniques to a greater degree. It would be worthwhile investigating how to enhance the performance of these techniques using more advanced acoustic modem platforms. The goal would be to build a more realistic UAN test-bed with 10 to 15 nodes.

APPENDIX A: CAPTURED TEXT FILE OF THE BUCKET TEST RESULTS FROM THE HYPER-TERMINAL APPLICATION

```
FREQUENCY DIVISION BUCKET TEST RESULTS

RECEIVED BY RBS-1 MODEM 2 (RECEIVER 2)

TEST DATA SEQUENCE 1 : 1234567890
TEST DATA SEQUENCE 2 : qwertyuiopasdfghjklzxcvbnm
TEST DATA SEQUENCE 3 : QWERTYUIOPASDFGHJKLZXCVBNM
TEST DATA SEQUENCE 4 : This is a test sentence.
TEST DATA SEQUENCE 5 : aaaassssddddffffgggghjhjhj
TEST DATA SEQUENCE 6 : zzzzxxxxccccvvvvbbbbnmnmnm
TEST DATA SEQUENCE 7 : qqqqqqqqqq

Transmitter 1 sends test sequence 1 through the water
--End of Line--

Transmitter 1 sends test sequence 2 through the water
--End of Line--

Transmitter 1 sends test sequence 3 through the water
--End of Line--

Transmitter 1 sends test sequence 4 through the water
--End of Line--

Transmitter 3 sends test sequence 1 through the water
1234567890--End of Line--

Transmitter 3 sends test sequence 2 through the water
qwertyuiopasdfghjklzxcvbnm--End of Line--

Transmitter 3 sends test sequence 3 through the water
QWERTYUIOPASDFGHJKLZXCVBNM--End of Line--

Transmitter 3 sends test sequence 4 through the water
This is a test sentence.--End of Line--

Transmitter  1  sends  test  sequence  5  and  transmitter  3  sends  test
sequence 6 through the water
zzzzxxxxccccvvvvbbbbnmnmnm--End of Line--

Transmitter  1  sends  test  sequence  6  and  transmitter  3  sends  test
sequence 5 through the water
aaaassssddddffffgggghjhjhj--End of Line--

Transmitter  1  sends  test  sequence  1  and  transmitter  3  sends  test
sequence 7 through the water
qqqqqqqqqq--End of Line--

Transmitter  1  sends  test  sequence  7  and  transmitter  3  sends  test
sequence 1 through the water
1234567890--End of Line--
```

```
DIRECT SEQUENCE CDMA BUCKET TEST RESULTS

RECEIVED BY RBS-1 MODEM 2 (RECEIVER 2)

TEST DATA SEQUENCE 1 : 1234567890
TEST DATA SEQUENCE 2 : qwertyuiopasdfghjklzxcvbnm
TEST DATA SEQUENCE 3 : QWERTYUIOPASDFGHJKLZXCVBNM
TEST DATA SEQUENCE 4 : This is a test sentence.
TEST DATA SEQUENCE 5 : aaaassssddddffffgggghjhjhj
TEST DATA SEQUENCE 6 : zzzzxxxxccccvvvvbbbbnmnmnm
TEST DATA SEQUENCE 7 : qqqqqqqqqq

Transmitter 1 sends test sequence 1 through the water
          --End of Line--

Transmitter 1 sends test sequence 2 through the water
                          --End of Line--

Transmitter 1 sends test sequence 2 through the water
                          --End of Line--

Transmitter 1 sends test sequence 4 through the water
                        --End of Line--

Transmitter 3 sends test sequence 1 through the water
1234567890--End of Line--

Transmitter 3 sends test sequence 2 through the water
qwertyuiopasdfghjklzxcvbnm--End of Line--

Transmitter 3 sends test sequence 3 through the water
QWERTYUIOPASDFGHJKLZXCVBNM--End of Line--

Transmitter 3 sends test sequence 4 through the water
This is a test sentence.--End of Line--

Transmitter  1  sends  test  sequence  5  and  transmitter  3  sends  test
sequence 6 through the water
ÿÿÿÿÿÿÿÿÿÿÿxÿÿÿÿÿÿÿÿÿÿÿÿÿÿ--End of Line--

Transmitter  1  sends  test  sequence  6  and  transmitter  3  sends  test
sequence 5 through the water
ÿÿÿÿxxxxÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿ--End of Line--

Transmitter  1  sends  test  sequence  1  and  transmitter  3  sends  test
sequence 7 through the water
ÿÿÿÿÿÿÿÿÿÿ--End of Line--

Transmitter  1  sends  test  sequence  7  and  transmitter  3  sends  test
sequence 1 through the water
ÿÿ-ÿxÿÿÿxÿ--End of Line--
```

DIRECT SEQUENCE CDMA BUCKET TEST RESULTS (SPEED OPTION:2)

RECEIVED BY RBS-1 MODEM 2 (RECEIVER 2)

TEST DATA SEQUENCE 1 : 1234567890
TEST DATA SEQUENCE 2 : qwertyuiopasdfghjklzxcvbnm
TEST DATA SEQUENCE 3 : QWERTYUIOPASDFGHJKLZXCVBNM
TEST DATA SEQUENCE 4 : This is a test sentence.
TEST DATA SEQUENCE 5 : aaaassssddddffffgggghjhjhj
TEST DATA SEQUENCE 6 : zzzzxxxxccccvvvvbbbbnmnmnm
TEST DATA SEQUENCE 7 : qqqqqqqqqq

Transmitter 1 sends test sequence 1 through the water
ÿÿÿÿÿÿÿÿÿÿ--End of Line--

Transmitter 1 sends test sequence 2 through the water
ÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿ--End of Line--

Transmitter 1 sends test sequence 3 through the water
ÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿ--End of Line--

Transmitter 1 sends test sequence 4 through the water
ÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿ--End of Line--

Transmitter 3 sends test sequence 1 through the water
1??4567??ð--End of Line--

Transmitter 3 sends test sequence 2 through the water
ñÿõòôÿõooposdÿÿÿÿoo□□cöboo--End of Line--

Transmitter 3 sends test sequence 3 through the water
QWõRTQUOOô□4Dôôôôôõõô?$ô--End of Line--

Transmitter 3 sends test sequence 4 through the water
_oÿóðaÿ ñ teót óeoôeoce/--End of Line--

Transmitter 1 sends test sequence 5 and transmitter 3 sends test sequence 6 through the water
ÿÿÿÿÿÿÿÿ<ÿÿ□ÿÿ□ÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿ--End of Line--

Transmitter 1 sends test sequence 6 and transmitter 3 sends test sequence 5 through the water
ÿÿÿÿ□ÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿ--End of Line--

Transmitter 1 sends test sequence 1 and transmitter 3 sends test sequence 7 through the water
xxÿÿÿÿÿÿÿÿ--End of Line--

Transmitter 1 sends test sequence 7 and transmitter 3 sends test sequence 1 through the water
ÿ<ÿÿÿ/ÿÿÿÿÿÿ--End of Line--

DIRECT SEQUENCE CDMA AND FREQUENCY DIVISION BUCKET TEST RESULTS

RECEIVED BY RBS-1 MODEM 2 (RECEIVER 2)

```
TEST DATA SEQUENCE 1 : 1234567890
TEST DATA SEQUENCE 2 : qwertyuiopasdfghjklzxcvbnm
TEST DATA SEQUENCE 3 : QWERTYUIOPASDFGHJKLZXCVBNM
TEST DATA SEQUENCE 4 : This is a test sentence.
TEST DATA SEQUENCE 5 : aaaassssddddffffgggghjhjhj
TEST DATA SEQUENCE 6 : zzzzxxxxccccvvvvbbbbnmnmnm
TEST DATA SEQUENCE 7 : qqqqqqqqqq
```

Transmitter 1 sends test sequence 1 through the water
--End of Line--

Transmitter 1 sends test sequence 2 through the water
--End of Line--

Transmitter 1 sends test sequence 3 through the water
--End of Line--

Transmitter 1 sends test sequence 4 through the water
--End of Line--

Transmitter 3 sends test sequence 1 through the water
1234567890--End of Line--

Transmitter 3 sends test sequence 2 through the water
qwertyuiopasdfghjklzxcvbnm--End of Line--

Transmitter 3 sends test sequence 3 through the water
QWERTYUIOPASDFGHJKLZXCVBNM--End of Line--

Transmitter 3 sends test sequence 4 through the water
This is a test sentence.--End of Line--

Transmitter 1 sends test sequence 5 and transmitter 3 sends test sequence 6 through the water
□zzzxxxxccccvvvvbbbbnmnmnm--End of Line--

Transmitter 1 sends test sequence 6 and transmitter 3 sends test sequence 5 through the water
aaaaÿ□ósdÿdôooöffgggohjhjhj--End of Line--

Transmitter 1 sends test sequence 1 and transmitter 3 sends test sequence 7 through the water
ñqqñ□qqñqq--End of Line--

Transmitter 1 sends test sequence 7 and transmitter 3 sends test sequence 1 through the water
123ô56?890--End of Line--

TIME HOPPING CDMA BUCKET TEST RESULTS

RECEIVED BY RBS-1 MODEM 2 (RECEIVER 2)

TEST DATA SEQUENCE 1 : 1234567890
TEST DATA SEQUENCE 2 : qwertyuiopasdfghjklzxcvbnm
TEST DATA SEQUENCE 3 : QWERTYUIOPASDFGHJKLZXCVBNM
TEST DATA SEQUENCE 4 : This is a test sentence.
TEST DATA SEQUENCE 5 : aaaassssddddffffgggghjhjhj
TEST DATA SEQUENCE 6 : zzzzxxxxccccvvvvbbbbnmnmnm
TEST DATA SEQUENCE 7 : qqqqqqqqqq

Transmitter 1 sends test sequence 1 through the water
--End of Line--

Transmitter 1 sends test sequence 2 through the water
--End of Line--

Transmitter 1 sends test sequence 3 through the water
--End of Line--

Transmitter 1 sends test sequence 4 through the water
ÿÿ--End of Line--

Transmitter 3 sends test sequence 1 through the water
1234567890--End of Line--

Transmitter 3 sends test sequence 2 through the water
qwertyuiopasdfghjklzxcvbÿÿ--End of Line--

Transmitter 3 sends test sequence 3 through the water
QWERTYUIOPASDFGHJKLZXCVBÿÿ--End of Line--

Transmitter 3 sends test sequence 4 through the water
This is a test sentence.--End of Line--

Transmitter 1 sends test sequence 5 and transmitter 3 sends test sequence 6 through the water
ÿÿÿÿÿÿÿÿ□ùÿÿccÿÿÿÿÿÿ□ðÿÿÿÿ--End of Line--

Transmitter 1 sends test sequence 6 and transmitter 3 sends test sequence 5 through the water
ÿÿÿÿÿÿÿÿÿÿddÿÿÿÿÿÿÿÿÿÿÿÿÿÿ--End of Line--

Transmitter 1 sends test sequence 1 and transmitter 3 sends test sequence 7 through the water
ÿÿÿÿ†³ÿÿÿÿÿÿ--End of Line--

Transmitter 1 sends test sequence 7 and transmitter 3 sends test sequence 1 through the water
ÿÿÿÿÿÿÿÿ--End of Line--

```
TIME HOPPING CDMA AND FREQUENCY DIVISION BUCKET TEST RESULTS

RECEIVED BY RBS-1 MODEM 2 (RECEIVER 2)

TEST DATA SEQUENCE 1 : 1234567890
TEST DATA SEQUENCE 2 : qwertyuiopasdfghjklzxcvbnm
TEST DATA SEQUENCE 3 : QWERTYUIOPASDFGHJKLZXCVBNM
TEST DATA SEQUENCE 4 : This is a test sentence.
TEST DATA SEQUENCE 5 : aaaassssddddffffgggghjhjhj
TEST DATA SEQUENCE 6 : zzzzxxxxccccvvvvbbbbnmnmnm
TEST DATA SEQUENCE 7 : qqqqqqqqqq

Transmitter 1 sends test sequence 1 through the water
--End of Line--

Transmitter 1 sends test sequence 2 through the water
--End of Line--

Transmitter 1 sends test sequence 3 through the water
--End of Line--

Transmitter 1 sends test sequence 4 through the water
--End of Line--

Transmitter 3 sends test sequence 1 through the water
1234567890--End of Line--

Transmitter 3 sends test sequence 2 through the water
qwertyuiopasdfghjklzxcvbÿÿ--End of Line--

Transmitter 3 sends test sequence 3 through the water
QWERTYUIOPASDFGHJKLZXCVBÿÿ--End of Line--

Transmitter 3 sends test sequence 4 through the water
This is a test sentence.--End of Line--

Transmitter 1 sends test sequence 5 and transmitter 3 sends test
sequence 6 through the water
zzzzxxÿÿÿÿÿÿvvÿÿbbbbnmnmÿÿ--End of Line--

Transmitter 1 sends test sequence 6 and transmitter 3 sends test
sequence 5 through the water
aaaassssddddffffgggghjhjhj--End of Line--

Transmitter 1 sends test sequence 1 and transmitter 3 sends test
sequence 7 through the water
qqqqqqqqqq--End of Line--

Transmitter 1 sends test sequence 7 and transmitter 3 sends test
sequence 1 through the water
1234567890--End of Line--
```

FREQUENCY HOPPING CDMA BUCKET TEST RESULTS

RECEIVED BY RBS-1 MODEM 2 (RECEIVER 2)

TEST DATA SEQUENCE 1 : 1234567890
TEST DATA SEQUENCE 2 : qwertyuiopasdfghjklzxcvbnm
TEST DATA SEQUENCE 3 : QWERTYUIOPASDFGHJKLZXCVBNM
TEST DATA SEQUENCE 4 : This is a test sentence.
TEST DATA SEQUENCE 5 : aaaassssddddffffgggghjhjhj
TEST DATA SEQUENCE 6 : zzzzxxxxccccvvvvbbbbnmnmnm
TEST DATA SEQUENCE 7 : qqqqqqqqqq

Transmitter 1 sends test sequence 1 through the water
ÿÿÿÿÿÿ78ÿÿ--End of Line--

Transmitter 1 sends test sequence 2 through the water
ÿÿÿÿÿÿÿÿÿÿÿÿdfÿÿÿÿÿÿÿÿÿÿnm--End of Line--

Transmitter 1 sends test sequence 3 through the water
ÿÿÿÿÿÿÿÿÿÿÿÿÿÿGHJKLZÿÿÿÿÿÿ--End of Line--

Transmitter 1 sends test sequence 4 through the water
ÿÿÿÿÿÿÿÿa teÿÿ sÿÿÿÿncÿÿ--End of Line--

Transmitter 3 sends test sequence 1 through the water
1234567890--End of Line--

Transmitter 3 sends test sequence 2 through the water
qwertyuiopasdfghjklzxcvbnm--End of Line--

Transmitter 3 sends test sequence 3 through the water
QWERTYUIOPASDFGHJKLZXCVBNM--End of Line--

Transmitter 3 sends test sequence 4 through the water
This is a test sentence.--End of Line--

Transmitter 1 sends test sequence 5 and transmitter 3 sends test sequence 6 through the water
ÿÿÿÿxxxxccccvvvvÿÿÿÿÿÿÿÿÿÿ--End of Line--

Transmitter 1 sends test sequence 6 and transmitter 3 sends test sequence 5 through the water
aaaaÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿ--End of Line--

Transmitter 1 sends test sequence 1 and transmitter 3 sends test sequence 7 through the water
ÿÿÿÿÿÿ!!ÿÿ--End of Line--

Transmitter 1 sends test sequence 7 and transmitter 3 sends test sequence 1 through the water
12ÿÿÿÿÿÿÿÿ--End of Line--

FREQUENCY HOPPING CDMA BUCKET TEST RESULTS (TRESHOLD:98)

RECEIVED BY RBS-1 MODEM 2 (RECEIVER 2)

TEST DATA SEQUENCE 1 : 1234567890
TEST DATA SEQUENCE 2 : qwertyuiopasdfghjklzxcvbnm
TEST DATA SEQUENCE 3 : QWERTYUIOPASDFGHJKLZXCVBNM
TEST DATA SEQUENCE 4 : This is a test sentence.
TEST DATA SEQUENCE 5 : aaaassssddddffffgggghjhjhj
TEST DATA SEQUENCE 6 : zzzzxxxxccccvvvvbbbbnmnmnm
TEST DATA SEQUENCE 7 : qqqqqqqqqq

Transmitter 1 sends test sequence 1 through the water
--End of Line--

Transmitter 1 sends test sequence 2 through the water
ÿÿÿÿÿÿÿÿÿÿ--End of Line--

Transmitter 1 sends test sequence 3 through the water
ÿÿÿÿÿÿÿÿ--End of Line--

Transmitter 1 sends test sequence 4 through the water
ÿÿÿÿÿÿÿÿÿÿÿÿÿÿ--End of Line--

Transmitter 3 sends test sequence 1 through the water
1234567890--End of Line--

Transmitter 3 sends test sequence 2 through the water
qwertyuiopasdfghjklzxcÿÿnm--End of Line--

Transmitter 3 sends test sequence 3 through the water
QWERTYUIOPASDFGHJKLZXCÿÿNM--End of Line--

Transmitter 3 sends test sequence 4 through the water
This is a test sentence.--End of Line--

Transmitter 1 sends test sequence 5 and transmitter 3 sends test sequence 6 through the water
zzzzxxxxccccvvvvbbÿÿÿÿnmnm--End of Line--

Transmitter 1 sends test sequence 6 and transmitter 3 sends test sequence 5 through the water
aaaassÿÿÿÿÿÿffffÿÿÿÿhjhjhj--End of Line--

Transmitter 1 sends test sequence 1 and transmitter 3 sends test sequence 7 through the water
ÿÿqqqqqqÿÿ--End of Line--

Transmitter 1 sends test sequence 7 and transmitter 3 sends test sequence 1 through the water
1234ÿÿÿÿÿÿ--End of Line--

FREQUENCY HOPPING CDMA AND FREQUENCY DIVISION BUCKET TEST RESULTS

RECEIVED BY RBS-1 MODEM 2 (RECEIVER 2)

TEST DATA SEQUENCE 1 : 1234567890
TEST DATA SEQUENCE 2 : qwertyuiopasdfghjklzxcvbnm
TEST DATA SEQUENCE 3 : QWERTYUIOPASDFGHJKLZXCVBNM
TEST DATA SEQUENCE 4 : This is a test sentence.
TEST DATA SEQUENCE 5 : aaaassssddddffffgggghjhjhj
TEST DATA SEQUENCE 6 : zzzzxxxxccccvvvvbbbbnmnmnm
TEST DATA SEQUENCE 7 : qqqqqqqqqq

Transmitter 1 sends test sequence 1 through the water
--End of Line--

Transmitter 1 sends test sequence 2 through the water
--End of Line--

Transmitter 1 sends test sequence 3 through the water
--End of Line--

Transmitter 1 sends test sequence 4 through the water
--End of Line--

Transmitter 3 sends test sequence 1 through the water
1234567890--End of Line--

Transmitter 3 sends test sequence 2 through the water
qwertyuiopasdfghjklzxcvbnm--End of Line--

Transmitter 3 sends test sequence 3 through the water
QWERTYUIOPASDFGHJKLZXCVBNM--End of Line--

Transmitter 3 sends test sequence 4 through the water
This is a test sentence.--End of Line--

Transmitter 1 sends test sequence 5 and transmitter 3 sends test sequence 6 through the water
zzzzxxxxccccvvvvÿÿbbÿÿnmnm--End of Line--

Transmitter 1 sends test sequence 6 and transmitter 3 sends test sequence 5 through the water
aaaaÿÿÿÿddddffffgggghjhjhj--End of Line--

Transmitter 1 sends test sequence 1 and transmitter 3 sends test sequence 7 through the water
qqÿÿqqqqÿÿ--End of Line--

Transmitter 1 sends test sequence 7 and transmitter 3 sends test sequence 1 through the water
1234567890--End of Line--

HYBRID (DS-TH) CDMA BUCKET TEST RESULTS

RECEIVED BY RBS-1 MODEM 2 (RECEIVER 2)

TEST DATA SEQUENCE 1 : 1234567890
TEST DATA SEQUENCE 2 : qwertyuiopasdfghjklzxcvbnm
TEST DATA SEQUENCE 3 : QWERTYUIOPASDFGHJKLZXCVBNM
TEST DATA SEQUENCE 4 : This is a test sentence.
TEST DATA SEQUENCE 5 : aaaassssddddffffgggghjhjhj
TEST DATA SEQUENCE 6 : zzzzxxxxccccvvvvbbbbnmnmnm
TEST DATA SEQUENCE 7 : qqqqqqqqqq

Transmitter 1 sends test sequence 1 through the water
--End of Line--

Transmitter 1 sends test sequence 2 through the water
--End of Line--

Transmitter 1 sends test sequence 3 through the water
ÿÿ--End of Line--

Transmitter 1 sends test sequence 4 through the water
ÿ--End of Line--

Transmitter 3 sends test sequence 1 through the water
1234567890--End of Line--

Transmitter 3 sends test sequence 2 through the water
qwertyuiopasdfghjklzxcvbnm--End of Line--

Transmitter 3 sends test sequence 3 through the water
QWERTYUIOPASDFGHJKLZXCVBNM--End of Line--

Transmitter 3 sends test sequence 4 through the water
This is a test sentence.--End of Line--

Transmitter 1 sends test sequence 5 and transmitter 3 sends test sequence 6 through the water
ÿÿÿÿ□z□ÿ□ÿÿÿÿÿÿÿÿòþÿÿÿÿÿ--End of Line--

Transmitter 1 sends test sequence 6 and transmitter 3 sends test sequence 5 through the water
ÿÿÿoÿÿ(ÿOÿÿÿÿÿÿÿÿÿÿÿoòoú--End of Line--

Transmitter 1 sends test sequence 1 and transmitter 3 sends test sequence 7 through the water
ÿÿÿÿ÷ÿÿÿ--End of Line--

Transmitter 1 sends test sequence 7 and transmitter 3 sends test sequence 1 through the water
óÿÿÿ?ÿÿóò□--End of Line--

HYBRID (DS-TH) CDMA AND FREQUENCY DIVISION BUCKET TEST RESULTS

RECEIVED BY RBS-1 MODEM 2 (RECEIVER 2)

TEST DATA SEQUENCE 1 : 1234567890
TEST DATA SEQUENCE 2 : qwertyuiopasdfghjklzxcvbnm
TEST DATA SEQUENCE 3 : QWERTYUIOPASDFGHJKLZXCVBNM
TEST DATA SEQUENCE 4 : This is a test sentence.
TEST DATA SEQUENCE 5 : aaaassssddddffffgggghjhjhj
TEST DATA SEQUENCE 6 : zzzzxxxxccccvvvvbbbbnmnmnm
TEST DATA SEQUENCE 7 : qqqqqqqqqq

Transmitter 1 sends test sequence 1 through the water
--End of Line--

Transmitter 1 sends test sequence 2 through the water
--End of Line--

Transmitter 1 sends test sequence 3 through the water
--End of Line--

Transmitter 1 sends test sequence 4 through the water
--End of Line--

Transmitter 3 sends test sequence 1 through the water
1234567890--End of Line--

Transmitter 3 sends test sequence 2 through the water
qwertyuiopasdfghjklzxcvbnm--End of Line--

Transmitter 3 sends test sequence 3 through the water
QWERTYUIOPASDFGHJKLZXCVBNM--End of Line--

Transmitter 3 sends test sequence 4 through the water
This is a test sentence.--End of Line--

Transmitter 1 sends test sequence 5 and transmitter 3 sends test sequence 6 through the water
zzzz□xxxóoccvvövbbbbnmöÖæ--End of Line--

Transmitter 1 sends test sequence 6 and transmitter 3 sends test sequence 5 through the water
Ö□□□□7776FFFFffffvvv□ö¦□ö†--End of Line--

Transmitter 1 sends test sequence 1 and transmitter 3 sends test sequence 7 through the water
§□□□□□□□□□--End of Line--

Transmitter 1 sends test sequence 7 and transmitter 3 sends test sequence 1 through the water
#3CScó□“--End of Line--

FREQUENCY DIVISION BUCKET TEST RESULTS

RECEIVED BY RBS-1 MODEM 4 (RECEIVER 4)

TEST DATA SEQUENCE 1 : 1234567890
TEST DATA SEQUENCE 2 : qwertyuiopasdfghjklzxcvbnm
TEST DATA SEQUENCE 3 : QWERTYUIOPASDFGHJKLZXCVBNM
TEST DATA SEQUENCE 4 : This is a test sentence.
TEST DATA SEQUENCE 5 : aaaassssddddffffgggghjhjhj
TEST DATA SEQUENCE 6 : zzzzxxxxccccvvvvbbbbnmnmnm
TEST DATA SEQUENCE 7 : qqqqqqqqqq

Transmitter 1 sends test sequence 1 through the water
1234567890--End of Line--

Transmitter 1 sends test sequence 2 through the water
qwertyuiopasdfghjklzxcvbnm--End of Line--

Transmitter 1 sends test sequence 3 through the water
QWERTYUIOPASDFGHJKLZXCVBNM--End of Line--

Transmitter 1 sends test sequence 4 through the water
This is a test sentence.--End of Line--

Transmitter 3 sends test sequence 1 through the water
--End of Line--

Transmitter 3 sends test sequence 2 through the water
--End of Line--

Transmitter 3 sends test sequence 3 through the water
--End of Line--

Transmitter 3 sends test sequence 4 through the water
--End of Line--

Transmitter 1 sends test sequence 5 and transmitter 3 sends test sequence 6 through the water
aaÿÿssssddÿÿffÿÿggggÿÿhjhj--End of Line--

Transmitter 1 sends test sequence 6 and transmitter 3 sends test sequence 5 through the water
zzzzÿÿxxÿÿÿÿvvvvÿÿbbnmnmnm--End of Line--

Transmitter 1 sends test sequence 1 and transmitter 3 sends test sequence 7 through the water
ÿÿ34567890--End of Line--

Transmitter 1 sends test sequence 7 and transmitter 3 sends test sequence 1 through the water
qqqqqqqqqq--End of Line--

```
DIRECT SEQUENCE CDMA BUCKET TEST RESULTS

RECEIVED BY RBS-1 MODEM 4 (RECEIVER 4)

TEST DATA SEQUENCE 1 : 1234567890
TEST DATA SEQUENCE 2 : qwertyuiopasdfghjklzxcvbnm
TEST DATA SEQUENCE 3 : QWERTYUIOPASDFGHJKLZXCVBNM
TEST DATA SEQUENCE 4 : This is a test sentence.
TEST DATA SEQUENCE 5 : aaaassssddddffffgggghjhjhj
TEST DATA SEQUENCE 6 : zzzzxxxxccccvvvvbbbbnmnmnm
TEST DATA SEQUENCE 7 : qqqqqqqqqq

Transmitter 1 sends test sequence 1 through the water
1234567890--End of Line--

Transmitter 1 sends test sequence 2 through the water
qwertyuiopasdfghjklzxcvbnm--End of Line--

Transmitter 1 sends test sequence 3 through the water
QWERTYUIOPASDFGHJKLZXCVBNM--End of Line--

Transmitter 1 sends test sequence 4 through the water
This is a test sentence.--End of Line--

Transmitter 3 sends test sequence 1 through the water
          --End of Line--

Transmitter 3 sends test sequence 2 through the water
                          --End of Line--

Transmitter 3 sends test sequence 3 through the water
                          --End of Line--

Transmitter 3 sends test sequence 4 through the water
                        --End of Line--

Transmitter 1 sends test sequence 5 and transmitter 3 sends test
sequence 6 through the water
                          --End of Line--

Transmitter 1 sends test sequence 6 and transmitter 3 sends test
sequence 5 through the water
                          --End of Line--

Transmitter 1 sends test sequence 1 and transmitter 3 sends test
sequence 7 through the water
          --End of Line--

Transmitter 1 sends test sequence 7 and transmitter 3 sends test
sequence 1 through the water
  □ □   □ --End of Line--
```

```
DIRECT SEQUENCE CDMA BUCKET TEST RESULTS (SPEED OPTION:2)

RECEIVED BY RBS-1 MODEM 4 (RECEIVER 4)

TEST DATA SEQUENCE 1 : 1234567890
TEST DATA SEQUENCE 2 : qwertyuiopasdfghjklzxcvbnm
TEST DATA SEQUENCE 3 : QWERTYUIOPASDFGHJKLZXCVBNM
TEST DATA SEQUENCE 4 : This is a test sentence.
TEST DATA SEQUENCE 5 : aaaassssddddffffgggghjhjhj
TEST DATA SEQUENCE 6 : zzzzxxxxccccvvvvbbbbnmnmnm
TEST DATA SEQUENCE 7 : qqqqqqqqqq

Transmitter 1 sends test sequence 1 through the water
    □     --End of Line--

Transmitter 1 sends test sequence 2 through the water
                      --End of Line--

Transmitter 1 sends test sequence 3 through the water
                          --End of Line--

Transmitter 1 sends test sequence 4 through the water
         □□        □  --End of Line--

Transmitter 3 sends test sequence 1 through the water
          --End of Line--

Transmitter 3 sends test sequence 2 through the water
                          --End of Line--

Transmitter 3 sends test sequence 3 through the water
                          --End of Line--

Transmitter 3 sends test sequence 4 through the water
                        --End of Line--

Transmitter  1  sends  test  sequence  5  and  transmitter  3  sends  test
sequence 6 through the water
                              --End of Line--

Transmitter  1  sends  test  sequence  6  and  transmitter  3  sends  test
sequence 5 through the water
                              --End of Line--

Transmitter  1  sends  test  sequence  1  and  transmitter  3  sends  test
sequence 7 through the water
□□        --End of Line--

Transmitter  1  sends  test  sequence  7  and  transmitter  3  sends  test
sequence 1 through the water
            --End of Line--
```

DIRECT SEQUENCE CDMA AND FREQUENCY DIVISION BUCKET TEST RESULTS

RECEIVED BY RBS-1 MODEM 4 (RECEIVER 4)

TEST DATA SEQUENCE 1 : 1234567890
TEST DATA SEQUENCE 2 : qwertyuiopasdfghjklzxcvbnm
TEST DATA SEQUENCE 3 : QWERTYUIOPASDFGHJKLZXCVBNM
TEST DATA SEQUENCE 4 : This is a test sentence.
TEST DATA SEQUENCE 5 : aaaassssddddffffgggghjhjhj
TEST DATA SEQUENCE 6 : zzzzxxxxccccvvvvbbbbnmnmnm
TEST DATA SEQUENCE 7 : qqqqqqqqqq

Transmitter 1 sends test sequence 1 through the water
12345□7□90--End of Line--

Transmitter 1 sends test sequence 2 through the water
qwertyuiopasdfghjklzxcvbnm--End of Line--

Transmitter 1 sends test sequence 3 through the water
QWERTYUIOPASDFGHJKLZXCVBNM--End of Line--

Transmitter 1 sends test sequence 4 through the water
This is a test sentence.--End of Line--

Transmitter 3 sends test sequence 1 through the water
--End of Line--

Transmitter 3 sends test sequence 2 through the water
  --End of Line--

Transmitter 3 sends test sequence 3 through the water
--End of Line--

Transmitter 3 sends test sequence 4 through the water
--End of Line--

Transmitter 1 sends test sequence 5 and transmitter 3 sends test sequence 6 through the water
aaaass□□d□□d□□fgggj□□--End of Line--

Transmitter 1 sends test sequence 6 and transmitter 3 sends test sequence 5 through the water
zxxccv□b□nm --End of Line--

Transmitter 1 sends test sequence 1 and transmitter 3 sends test sequence 7 through the water
1□3□567□9--End of Line--

Transmitter 1 sends test sequence 7 and transmitter 3 sends test sequence 1 through the water
 □q□qqq--End of Line--

TIME HOPPING CDMA BUCKET TEST RESULTS

RECEIVED BY RBS-1 MODEM 4 (RECEIVER 4)

TEST DATA SEQUENCE 1 : 1234567890
TEST DATA SEQUENCE 2 : qwertyuiopasdfghjklzxcvbnm
TEST DATA SEQUENCE 3 : QWERTYUIOPASDFGHJKLZXCVBNM
TEST DATA SEQUENCE 4 : This is a test sentence.
TEST DATA SEQUENCE 5 : aaaassssddddffffgggghjhjhj
TEST DATA SEQUENCE 6 : zzzzxxxxccccvvvvbbbbnmnmnm
TEST DATA SEQUENCE 7 : qqqqqqqqqq

Transmitter 1 sends test sequence 1 through the water
1234567890--End of Line--

Transmitter 1 sends test sequence 2 through the water
qwertyuiopasdfghjklzxcvbnm--End of Line--

Transmitter 1 sends test sequence 3 through the water
QWERTYUIOPASDFGHJKLZXCVBNM--End of Line--

Transmitter 1 sends test sequence 4 through the water
This is a test sentence.--End of Line--

Transmitter 3 sends test sequence 1 through the water
--End of Line--

Transmitter 3 sends test sequence 2 through the water
ÿÿÿÿ--End of Line--

Transmitter 3 sends test sequence 3 through the water
ÿÿÿÿ--End of Line--

Transmitter 3 sends test sequence 4 through the water
ÿÿÿÿÿÿ--End of Line--

Transmitter 1 sends test sequence 5 and transmitter 3 sends test sequence 6 through the water
ÿÿÿÿÿÿÿÿ□Qÿÿÿÿÿÿÿÿhjhj--End of Line--

Transmitter 1 sends test sequence 6 and transmitter 3 sends test sequence 5 through the water
ÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿnmnm--End of Line--

Transmitter 1 sends test sequence 1 and transmitter 3 sends test sequence 7 through the water
ÿÿÿÿÿÿ90--End of Line--

Transmitter 1 sends test sequence 7 and transmitter 3 sends test sequence 1 through the water
ÿÿÿÿÿÿqq--End of Line--

TIME HOPPING CDMA AND FREQUENCY DIVISION BUCKET TEST RESULTS

RECEIVED BY RBS-1 MODEM 4 (RECEIVER 4)

TEST DATA SEQUENCE 1 : 1234567890
TEST DATA SEQUENCE 2 : qwertyuiopasdfghjklzxcvbnm
TEST DATA SEQUENCE 3 : QWERTYUIOPASDFGHJKLZXCVBNM
TEST DATA SEQUENCE 4 : This is a test sentence.
TEST DATA SEQUENCE 5 : aaaassssddddffffgggghjhjhj
TEST DATA SEQUENCE 6 : zzzzxxxxccccvvvvbbbbnmnmnm
TEST DATA SEQUENCE 7 : qqqqqqqqqq

Transmitter 1 sends test sequence 1 through the water
1234567890--End of Line--

Transmitter 1 sends test sequence 2 through the water
qwertyuiopasdfghjklzxcvbnm--End of Line--

Transmitter 1 sends test sequence 3 through the water
QWERTYUIOPASDFGHJKLZXCVBNM--End of Line--

Transmitter 1 sends test sequence 4 through the water
This is a test sentence.--End of Line--

Transmitter 3 sends test sequence 1 through the water
--End of Line--

Transmitter 3 sends test sequence 2 through the water
--End of Line--

Transmitter 3 sends test sequence 3 through the water
--End of Line--

Transmitter 3 sends test sequence 4 through the water
--End of Line--

Transmitter 1 sends test sequence 5 and transmitter 3 sends test sequence 6 through the water
aaÿÿssssÿÿÿÿffÿÿggÿÿhjhj--End of Line--

Transmitter 1 sends test sequence 6 and transmitter 3 sends test sequence 5 through the water
zzÿÿÿÿÿÿccÿÿÿÿbbÿÿnmnm--End of Line--

Transmitter 1 sends test sequence 1 and transmitter 3 sends test sequence 7 through the water
ÿÿ34567890--End of Line--

Transmitter 1 sends test sequence 7 and transmitter 3 sends test sequence 1 through the water
qqqqqqqqqq--End of Line--

FREQUENCY HOPPING CDMA BUCKET TEST RESULTS

RECEIVED BY RBS-1 MODEM 4 (RECEIVER 4)

TEST DATA SEQUENCE 1 : 1234567890
TEST DATA SEQUENCE 2 : qwertyuiopasdfghjklzxcvbnm
TEST DATA SEQUENCE 3 : QWERTYUIOPASDFGHJKLZXCVBNM
TEST DATA SEQUENCE 4 : This is a test sentence.
TEST DATA SEQUENCE 5 : aaaassssddddffffgggghjhjhj
TEST DATA SEQUENCE 6 : zzzzxxxxccccvvvvbbbbnmnmnm
TEST DATA SEQUENCE 7 : qqqqqqqqqq

Transmitter 1 sends test sequence 1 through the water
1234567890--End of Line--

Transmitter 1 sends test sequence 2 through the water
qwertyuiopasdfghjklzxcvbnm--End of Line--

Transmitter 1 sends test sequence 3 through the water
QWERTYUIOPASDFGHJKLZXCVBNM--End of Line--

Transmitter 1 sends test sequence 4 through the water
This is a test sentence.--End of Line--

Transmitter 3 sends test sequence 1 through the water
123456ÿÿÿÿ--End of Line--

Transmitter 3 sends test sequence 2 through the water
qwerÿÿÿÿopasÿÿÿÿjklzxcÿÿÿÿ--End of Line--

Transmitter 3 sends test sequence 3 through the water
QWÿÿÿÿUIOPASÿÿÿÿJKÿÿÿÿÿÿNM--End of Line--

Transmitter 3 sends test sequence 4 through the water
ÿÿis iÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿ--End of Line--

Transmitter 1 sends test sequence 5 and transmitter 3 sends test sequence 6 through the water
ÿÿÿÿxxxxÿÿÿÿvvÿÿÿÿÿÿn}ÿÿn}--End of Line--

Transmitter 1 sends test sequence 6 and transmitter 3 sends test sequence 5 through the water
aaaaÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿhjhjhj--End of Line--

Transmitter 1 sends test sequence 1 and transmitter 3 sends test sequence 7 through the water
ÿÿÿÿÿÿÿÿÿÿ--End of Line--

Transmitter 1 sends test sequence 7 and transmitter 3 sends test sequence 1 through the water
12ÿÿÿÿÿÿÿÿ--End of Line--

FREQUENCY HOPPING CDMA BUCKET TEST RESULTS (TRESHOLD:90)

RECEIVED BY RBS-1 MODEM 4 (RECEIVER 4)

TEST DATA SEQUENCE 1 : 1234567890
TEST DATA SEQUENCE 2 : qwertyuiopasdfghjklzxcvbnm
TEST DATA SEQUENCE 3 : QWERTYUIOPASDFGHJKLZXCVBNM
TEST DATA SEQUENCE 4 : This is a test sentence.
TEST DATA SEQUENCE 5 : aaaassssddddffffgggghjhjhj
TEST DATA SEQUENCE 6 : zzzzxxxxccccvvvvbbbbnmnmnm
TEST DATA SEQUENCE 7 : qqqqqqqqqq

Transmitter 1 sends test sequence 1 through the water
12ÿÿ567890--End of Line--

Transmitter 1 sends test sequence 2 through the water
qwertyuiopasdfghjkÿÿxcvbnm--End of Line--

Transmitter 1 sends test sequence 3 through the water
QWERTYUIOPASDFGHJKÿÿXCVBÿÿ--End of Line--

Transmitter 1 sends test sequence 4 through the water
This is a test sentence.--End of Line--

Transmitter 3 sends test sequence 1 through the water
ÿÿ--End of Line--

Transmitter 3 sends test sequence 2 through the water
ÿÿÿÿÿÿÿÿÿÿÿÿÿÿ--End of Line--

Transmitter 3 sends test sequence 3 through the water
ÿÿÿÿÿÿÿÿÿÿ--End of Line--

Transmitter 3 sends test sequence 4 through the water
ÿÿÿÿÿÿÿÿÿÿÿÿÿÿ--End of Line--

Transmitter 1 sends test sequence 5 and transmitter 3 sends test sequence 6 through the water
aaÿÿssssddddffffggÿÿÿÿÿÿhj--End of Line--

Transmitter 1 sends test sequence 6 and transmitter 3 sends test sequence 5 through the water
zzzzxxÿÿccccÿÿÿÿbbbbnmnmnm--End of Line--

Transmitter 1 sends test sequence 1 and transmitter 3 sends test sequence 7 through the water
1234567890--End of Line--

Transmitter 1 sends test sequence 7 and transmitter 3 sends test sequence 1 through the water
ÿÿÿÿqqqqqq--End of Line--

FREQUENCY HOPPING CDMA AND FREQUENCY DIVISION BUCKET TEST RESULTS

RECEIVED BY RBS-1 MODEM 4 (RECEIVER 4)

TEST DATA SEQUENCE 1 : 1234567890
TEST DATA SEQUENCE 2 : qwertyuiopasdfghjklzxcvbnm
TEST DATA SEQUENCE 3 : QWERTYUIOPASDFGHJKLZXCVBNM
TEST DATA SEQUENCE 4 : This is a test sentence.
TEST DATA SEQUENCE 5 : aaaassssddddffffgggghjhjhj
TEST DATA SEQUENCE 6 : zzzzxxxxccccvvvvbbbbnmnmnm
TEST DATA SEQUENCE 7 : qqqqqqqqqq

Transmitter 1 sends test sequence 1 through the water
1234567890--End of Line--

Transmitter 1 sends test sequence 2 through the water
qwertyuiopasdfghjklzxcvbnm--End of Line--

Transmitter 1 sends test sequence 3 through the water
QWERTYUIOPASDFGHJKLZXCVBNM--End of Line--

Transmitter 1 sends test sequence 4 through the water
This is a test sentence.--End of Line--

Transmitter 3 sends test sequence 1 through the water
--End of Line--

Transmitter 3 sends test sequence 2 through the water
--End of Line--

Transmitter 3 sends test sequence 3 through the water
--End of Line--

Transmitter 3 sends test sequence 4 through the water
--End of Line--

Transmitter 1 sends test sequence 5 and transmitter 3 sends test sequence 6 through the water
ÿÿÿÿÿÿssddddffffgggghjÿÿÿÿ--End of Line--

Transmitter 1 sends test sequence 6 and transmitter 3 sends test sequence 5 through the water
zzzzxxxxccccvvvvbbbbnmnmnm--End of Line--

Transmitter 1 sends test sequence 1 and transmitter 3 sends test sequence 7 through the water
1234567890--End of Line--

Transmitter 1 sends test sequence 7 and transmitter 3 sends test sequence 1 through the water
qqqqqqqqqq--End of Line--

```
HYBRID (DS-TH) CDMA BUCKET TEST RESULTS

RECEIVED BY RBS-1 MODEM 4 (RECEIVER 4)

TEST DATA SEQUENCE 1 : 1234567890
TEST DATA SEQUENCE 2 : qwertyuiopasdfghjklzxcvbnm
TEST DATA SEQUENCE 3 : QWERTYUIOPASDFGHJKLZXCVBNM
TEST DATA SEQUENCE 4 : This is a test sentence.
TEST DATA SEQUENCE 5 : aaaassssddddffffgggghjhjhj
TEST DATA SEQUENCE 6 : zzzzxxxxccccvvvvbbbbnmnmnm
TEST DATA SEQUENCE 7 : qqqqqqqqqq

Transmitter 1 sends test sequence 1 through the water
1234567890--End of Line--

Transmitter 1 sends test sequence 2 through the water
qwertyuiopasdfghjklzxcvbnm--End of Line--

Transmitter 1 sends test sequence 3 through the water
QWERTYUIOPASDFGHJKLZXCVBNM--End of Line--

Transmitter 1 sends test sequence 4 through the water
This is a test sentence.--End of Line--

Transmitter 3 sends test sequence 1 through the water
     --End of Line--

Transmitter 3 sends test sequence 2 through the water
               --End of Line--

Transmitter 3 sends test sequence 3 through the water
      --End of Line--

Transmitter 3 sends test sequence 4 through the water
           --End of Line--

Transmitter 1 sends test sequence 5 and transmitter 3 sends test
sequence 6 through the water
                     ¦†¦†--End of Line--

Transmitter 1 sends test sequence 6 and transmitter 3 sends test
sequence 5 through the water
□                    □æÖæ--End of Line--

Transmitter 1 sends test sequence 1 and transmitter 3 sends test
sequence 7 through the water
□  □    “--End of Line--

Transmitter 1 sends test sequence 7 and transmitter 3 sends test
sequence 1 through the water
      □q--End of Line--
```

HYBRID (DS-TH) CDMA AND FREQUENCY DIVISION BUCKET TEST RESULTS

RECEIVED BY RBS-1 MODEM 4 (RECEIVER 4)

TEST DATA SEQUENCE 1 : 1234567890
TEST DATA SEQUENCE 2 : qwertyuiopasdfghjklzxcvbnm
TEST DATA SEQUENCE 3 : QWERTYUIOPASDFGHJKLZXCVBNM
TEST DATA SEQUENCE 4 : This is a test sentence.
TEST DATA SEQUENCE 5 : aaaassssddddffffgggghjhjhj
TEST DATA SEQUENCE 6 : zzzzxxxxccccvvvvbbbbnmnmnm
TEST DATA SEQUENCE 7 : qqqqqqqqqq

Transmitter 1 sends test sequence 1 through the water
1234567890--End of Line--

Transmitter 1 sends test sequence 2 through the water
qwertyuiopasdfghjklzxcvbnm--End of Line--

Transmitter 1 sends test sequence 3 through the water
QWERTYUIOPASDFGHJKLZXCVBNM--End of Line--

Transmitter 1 sends test sequence 4 through the water
This is a test sentence.--End of Line--

Transmitter 3 sends test sequence 1 through the water
--End of Line--

Transmitter 3 sends test sequence 2 through the water
--End of Line--

Transmitter 3 sends test sequence 3 through the water
--End of Line--

Transmitter 3 sends test sequence 4 through the water
--End of Line--

Transmitter 1 sends test sequence 5 and transmitter 3 sends test sequence 6 through the water
 □aa□sssddddfff□gghjhjhj--End of Line--

Transmitter 1 sends test sequence 6 and transmitter 3 sends test sequence 5 through the water
zzzx□x□□ccvb□ mnmnm--End of Line--

Transmitter 1 sends test sequence 1 and transmitter 3 sends test sequence 7 through the water
□234567□90--End of Line--

Transmitter 1 sends test sequence 7 and transmitter 3 sends test sequence 1 through the water
□□qqq--End of Line--

APPENDIX B: CAPTURED TEXT FILE OF THE LAKE TEST RESULTS FROM THE HYPER-TERMINAL APPLICATION

```
FREQUENCY DIVISION LAKE TEST RESULTS

RECEIVED BY RBS-1 MODEM 2 (RECEIVER 2)

TEST DATA SEQUENCE 1 : 1234567890
TEST DATA SEQUENCE 2 : qwertyuiopasdfghjklzxcvbnm
TEST DATA SEQUENCE 3 : QWERTYUIOPASDFGHJKLZXCVBNM
TEST DATA SEQUENCE 4 : This is a test sentence.
TEST DATA SEQUENCE 5 : aaaassssddddffffgggghjhjhj
TEST DATA SEQUENCE 6 : zzzzxxxxccccvvvvbbbbnmnmnm
TEST DATA SEQUENCE 7 : qqqqqqqqqq

Transmitter 1 sends test sequence 1 through the water
--End of Line--

Transmitter 1 sends test sequence 2 through the water
--End of Line--

Transmitter 1 sends test sequence 3 through the water
--End of Line--

Transmitter 1 sends test sequence 4 through the water
--End of Line--

Transmitter 3 sends test sequence 1 through the water
1234567890--End of Line--

Transmitter 3 sends test sequence 2 through the water
qwertyuiopasdfghjklzxcvbnm--End of Line--

Transmitter 3 sends test sequence 3 through the water
QWERTYUIOPASDFGHJKLZXCVBNM--End of Line--

Transmitter 3 sends test sequence 4 through the water
This is a test sentence.--End of Line--

Transmitter  1  sends  test  sequence  5  and  transmitter  3  sends  test
sequence 6 through the water
zzzzxxxxccÿÿvvvvbbbbnmnmÿÿ--End of Line--

Transmitter  1  sends  test  sequence  6  and  transmitter  3  sends  test
sequence 5 through the water
ÿÿaassssddddffffggÿÿhjhjhj--End of Line--

Transmitter  1  sends  test  sequence  1  and  transmitter  3  sends  test
sequence 7 through the water
qqqqqqqqqq--End of Line--

Transmitter  1  sends  test  sequence  7  and  transmitter  3  sends  test
sequence 1 through the water
1234567890--End of Line--
```

```
DIRECT SEQUENCE CDMA LAKE TEST RESULTS

RECEIVED BY RBS-1 MODEM 2 (RECEIVER 2)

TEST DATA SEQUENCE 1 : 1234567890
TEST DATA SEQUENCE 2 : qwertyuiopasdfghjklzxcvbnm
TEST DATA SEQUENCE 3 : QWERTYUIOPASDFGHJKLZXCVBNM
TEST DATA SEQUENCE 4 : This is a test sentence.
TEST DATA SEQUENCE 5 : aaaassssddddffffgggghjhjhj
TEST DATA SEQUENCE 6 : zzzzxxxxccccvvvvbbbbnmnmnm
TEST DATA SEQUENCE 7 : qqqqqqqqqq

Transmitter 1 sends test sequence 1 through the water
          --End of Line--

Transmitter 1 sends test sequence 2 through the water
                          --End of Line--

Transmitter 1 sends test sequence 3 through the water
                          --End of Line--

Transmitter 1 sends test sequence 4 through the water
                        --End of Line--

Transmitter 3 sends test sequence 1 through the water
1234567890--End of Line--

Transmitter 3 sends test sequence 2 through the water
qwertyuiopasdfghjklzxcvbnm--End of Line--

Transmitter 3 sends test sequence 3 through the water
QWERTYUIOPASDFGHJKLZXCVBNM--End of Line--

Transmitter 3 sends test sequence 4 through the water
This is a test sentence.--End of Line--

Transmitter 1 sends test sequence 5 and transmitter 3 sends test
sequence 6 through the water
□□□□ÿÿÿÿ□□□□   □□□□□    nm--End of Line--

Transmitter 1 sends test sequence 6 and transmitter 3 sends test
sequence 5 through the water
ÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿ-ÿÿÿÿÿÿ--End of Line--

Transmitter 1 sends test sequence 1 and transmitter 3 sends test
sequence 7 through the water
ÿÿÿÿ□ÿÿÿÿÿ--End of Line--

Transmitter 1 sends test sequence 7 and transmitter 3 sends test
sequence 1 through the water
ÿÿÿÿÿÿÿÿÿ ÿÿÿÿ--End of Line--
```

DIRECT SEQUENCE CDMA LAKE TEST RESULTS (SPEED OPTION:2)

RECEIVED BY RBS-1 MODEM 2 (RECEIVER 2)

TEST DATA SEQUENCE 1 : 1234567890
TEST DATA SEQUENCE 2 : qwertyuiopasdfghjklzxcvbnm
TEST DATA SEQUENCE 3 : QWERTYUIOPASDFGHJKLZXCVBNM
TEST DATA SEQUENCE 4 : This is a test sentence.
TEST DATA SEQUENCE 5 : aaaassssddddffffgggghjhjhj
TEST DATA SEQUENCE 6 : zzzzxxxxccccvvvvbbbbnmnmnm
TEST DATA SEQUENCE 7 : qqqqqqqqqq

Transmitter 1 sends test sequence 1 through the water
ÿÿÿÿÿÿ□ÿÿ□--End of Line--

Transmitter 1 sends test sequence 2 through the water
ÿÿÿ□□- -□ □□□ ÿÿ ÿÿ□ --ÿÿ--End of Line--

Transmitter 1 sends test sequence 3 through the water
ÿÿÿ-ÿ□ÿ□ÿÿÿÿÿÿÿÿÿÿÿÿ□ÿÿÿÿÿÿ--End of Line--

Transmitter 1 sends test sequence 4 through the water
ÿÿÿÿÿÿÿÿÿÿÿÿÿ□ÿÿÿÿÿÿÿÿÿ-ÿ--End of Line--

Transmitter 3 sends test sequence 1 through the water
ó#3CScsóó□--End of Line--

Transmitter 3 sends test sequence 2 through the water
□vW'G÷Vö÷□□6Ffvööö÷÷ö7f&öõ--End of Line--

Transmitter 3 sends test sequence 3 through the water
□tU%EõTôõ□□4Ddtôôôõõô5d$ôõ--End of Line--

Transmitter 3 sends test sequence 4 through the water
Fö÷2□÷2□□□FW7B□6V÷FVö6Rÿ--End of Line--

Transmitter 1 sends test sequence 5 and transmitter 3 sends test sequence 6 through the water
ÿÿÿÿÿÿöÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿ--End of Line--

Transmitter 1 sends test sequence 6 and transmitter 3 sends test sequence 5 through the water
ÿÿÿÿÿÿÿÿÿÿÿÿxÿÿÿÿÿÿÿÿÿÿÿÿÿÿ--End of Line--

Transmitter 1 sends test sequence 1 and transmitter 3 sends test sequence 7 through the water
ÿÿÿÿÿÿÿÿÿÿ--End of Line--

Transmitter 1 sends test sequence 7 and transmitter 3 sends test sequence 1 through the water
ÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿ/ÿÿÿÿ--End of Line--

DIRECT SEQUENCE CDMA AND FREQUENCY DIVISION LAKE TEST RESULTS

RECEIVED BY RBS-1 MODEM 2 (RECEIVER 2)

TEST DATA SEQUENCE 1 : 1234567890
TEST DATA SEQUENCE 2 : qwertyuiopasdfghjklzxcvbnm
TEST DATA SEQUENCE 3 : QWERTYUIOPASDFGHJKLZXCVBNM
TEST DATA SEQUENCE 4 : This is a test sentence.
TEST DATA SEQUENCE 5 : aaaassssddddffffgggghjhjhj
TEST DATA SEQUENCE 6 : zzzzxxxxccccvvvvbbbbnmnmnm
TEST DATA SEQUENCE 7 : qqqqqqqqq

Transmitter 1 sends test sequence 1 through the water
--End of Line--

Transmitter 1 sends test sequence 2 through the water
--End of Line--

Transmitter 1 sends test sequence 3 through the water
--End of Line--

Transmitter 1 sends test sequence 4 through the water
--End of Line--

Transmitter 3 sends test sequence 1 through the water
1234567890--End of Line--

Transmitter 3 sends test sequence 2 through the water
qwertyuiopasdfghjklzxcvbnm--End of Line--

Transmitter 3 sends test sequence 3 through the water
QWERTYUIOPASDFGHJKLZXCVBNM--End of Line--

Transmitter 3 sends test sequence 4 through the water
This is a test sentence.--End of Line--

Transmitter 1 sends test sequence 5 and transmitter 3 sends test sequence 6 through the water
zzzzxxxxccccvvvvbòbbnmnmnm--End of Line--

Transmitter 1 sends test sequence 6 and transmitter 3 sends test sequence 5 through the water
oañ÷?776FFFFffffvvvv†¦†¦†--End of Line--

Transmitter 1 sends test sequence 1 and transmitter 3 sends test sequence 7 through the water
§qqqqqqqq--End of Line--

Transmitter 1 sends test sequence 7 and transmitter 3 sends test sequence 1 through the water
1234CScsƒ“--End of Line--

TIME HOPPING CDMA LAKE TEST RESULTS

RECEIVED BY RBS-1 MODEM 2 (RECEIVER 2)

TEST DATA SEQUENCE 1 : 1234567890
TEST DATA SEQUENCE 2 : qwertyuiopasdfghjklzxcvbnm
TEST DATA SEQUENCE 3 : QWERTYUIOPASDFGHJKLZXCVBNM
TEST DATA SEQUENCE 4 : This is a test sentence.
TEST DATA SEQUENCE 5 : aaaassssddddffffgggghjhjhj
TEST DATA SEQUENCE 6 : zzzzxxxxccccvvvvbbbbnmnmnm
TEST DATA SEQUENCE 7 : qqqqqqqqqq

Transmitter 1 sends test sequence 1 through the water
ÿÿÿÿÿÿÿÿÿÿ--End of Line--

Transmitter 1 sends test sequence 1 through the water
ÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿ--End of Line--

Transmitter 1 sends test sequence 1 through the water
ÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿ--End of Line--

Transmitter 1 sends test sequence 1 through the water
ÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿ--End of Line--

Transmitter 3 sends test sequence 1 through the water
1234567890--End of Line--

Transmitter 3 sends test sequence 2 through the water
qwertyuiopasdfghjklzxcvbÿÿ--End of Line--

Transmitter 3 sends test sequence 3 through the water
ÿÿERTYUIOPASÿÿGHJKLZXCVBNM--End of Line--

Transmitter 3 sends test sequence 4 through the water
This is a test sentence.--End of Line--

Transmitter 1 sends test sequence 5 and transmitter 3 sends test sequence 6 through the water
ÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿ--End of Line--

Transmitter 1 sends test sequence 6 and transmitter 3 sends test sequence 5 through the water
aaÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿ °--End of Line--

Transmitter 1 sends test sequence 1 and transmitter 3 sends test sequence 7 through the water
ÿÿÿÿÿÿÿÿ--End of Line--

Transmitter 1 sends test sequence 7 and transmitter 3 sends test sequence 1 through the water
ÿÿ34ÿÿ x□ñÿÿ--End of Line--

TIME HOPPING CDMA AND FREQUENCY DIVISION LAKE TEST RESULTS

RECEIVED BY RBS-1 MODEM 2 (RECEIVER 2)

TEST DATA SEQUENCE 1 : 1234567890
TEST DATA SEQUENCE 2 : qwertyuiopasdfghjklzxcvbnm
TEST DATA SEQUENCE 3 : QWERTYUIOPASDFGHJKLZXCVBNM
TEST DATA SEQUENCE 4 : This is a test sentence.
TEST DATA SEQUENCE 5 : aaaassssddddffffgggghjhjhj
TEST DATA SEQUENCE 6 : zzzzxxxxccccvvvvbbbbnmnmnm
TEST DATA SEQUENCE 7 : qqqqqqqqqq

Transmitter 1 sends test sequence 1 through the water
--End of Line--

Transmitter 1 sends test sequence 2 through the water
--End of Line--

Transmitter 1 sends test sequence 3 through the water
--End of Line--

Transmitter 1 sends test sequence 4 through the water
--End of Line--

Transmitter 3 sends test sequence 1 through the water
1234567890--End of Line--

Transmitter 3 sends test sequence 2 through the water
qwertyuiopasdfghjklzxcvbÿÿ--End of Line--

Transmitter 3 sends test sequence 3 through the water
ÿÿERTYUIOPASÿÿGHJKLZXCVBÿÿ--End of Line--

Transmitter 3 sends test sequence 4 through the water
This is a test sentence.--End of Line--

Transmitter 1 sends test sequence 5 and transmitter 3 sends test sequence 6 through the water
ÿÿÿÿxxxxccÿÿvvvvbbbbÿÿÿÿÿÿ--End of Line--

Transmitter 1 sends test sequence 6 and transmitter 3 sends test sequence 5 through the water
aaaassÿÿddddffffgggghjhjÿÿ--End of Line--

Transmitter 1 sends test sequence 1 and transmitter 3 sends test sequence 7 through the water
ÿÿÿÿqqqqqq--End of Line--

Transmitter 1 sends test sequence 7 and transmitter 3 sends test sequence 1 through the water
123456ÿÿ90--End of Line--

FREQUENCY HOPPING CDMA LAKE TEST RESULTS

RECEIVED BY RBS-1 MODEM 2 (RECEIVER 2)

```
TEST DATA SEQUENCE 1 : 1234567890
TEST DATA SEQUENCE 2 : qwertyuiopasdfghjklzxcvbnm
TEST DATA SEQUENCE 3 : QWERTYUIOPASDFGHJKLZXCVBNM
TEST DATA SEQUENCE 4 : This is a test sentence.
TEST DATA SEQUENCE 5 : aaaassssddddffffgggghjhjhj
TEST DATA SEQUENCE 6 : zzzzxxxxccccvvvvbbbbnmnmnm
TEST DATA SEQUENCE 7 : qqqqqqqqqq
```

Transmitter 1 sends test sequence 1 through the water
12ÿÿ56ÿÿ90--End of Line--

Transmitter 1 sends test sequence 2 through the water
ÿÿÿÿtyuiopasdfghjkÿÿxcvbÿÿ--End of Line--

Transmitter 1 sends test sequence 3 through the water
QWÿÿTYÿÿOPÿÿDFGHJKÿÿÿÿVBÿÿ--End of Line--

Transmitter 1 sends test sequence 4 through the water
ÿÿÿÿÿÿÿÿÿÿtestÿÿentence.--End of Line--

Transmitter 3 sends test sequence 1 through the water
1234567890--End of Line--

Transmitter 3 sends test sequence 2 through the water
qwertyuiopasdfghjklzxcvbnm--End of Line--

Transmitter 3 sends test sequence 3 through the water
QWERTYUIOPASDFGHJKLZXCVBNM--End of Line--

Transmitter 3 sends test sequence 4 through the water
This is a test sentence.--End of Line--

Transmitter 1 sends test sequence 5 and transmitter 3 sends test sequence 6 through the water
aaÿÿÿÿÿÿddÿÿÿÿffggÿÿhjhjhj--End of Line--

Transmitter 1 sends test sequence 6 and transmitter 3 sends test sequence 5 through the water
ÿÿaaÿÿÿÿddddffffÿÿÿÿhjhjhj--End of Line--

Transmitter 1 sends test sequence 1 and transmitter 3 sends test sequence 7 through the water
12ÿÿÿÿÿÿÿÿ--End of Line--

Transmitter 1 sends test sequence 7 and transmitter 3 sends test sequence 1 through the water
ÿÿÿÿqqÿÿÿÿ--End of Line--

FREQUENCY HOPPING CDMA LAKE TEST RESULTS (TRESHOLD:98)

RECEIVED BY RBS-1 MODEM 2 (RECEIVER 2)

```
TEST DATA SEQUENCE 1 : 1234567890
TEST DATA SEQUENCE 2 : qwertyuiopasdfghjklzxcvbnm
TEST DATA SEQUENCE 3 : QWERTYUIOPASDFGHJKLZXCVBNM
TEST DATA SEQUENCE 4 : This is a test sentence.
TEST DATA SEQUENCE 5 : aaaassssddddffffgggghjhjhj
TEST DATA SEQUENCE 6 : zzzzxxxxccccvvvvbbbbnmnmnm
TEST DATA SEQUENCE 7 : qqqqqqqqqq
```

Transmitter 1 sends test sequence 1 through the water
ÿÿÿÿ--End of Line--

Transmitter 1 sends test sequence 2 through the water
ÿÿÿÿÿÿÿÿÿÿ--End of Line--

Transmitter 1 sends test sequence 3 through the water
ÿÿÿÿÿÿÿÿÿÿ--End of Line--

Transmitter 1 sends test sequence 4 through the water
ÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿ--End of Line--

Transmitter 3 sends test sequence 1 through the water
1234567890--End of Line--

Transmitter 3 sends test sequence 1 through the water
qwertyuiopasdfghjklzxcvbnm--End of Line--

Transmitter 3 sends test sequence 1 through the water
QWERTYUIOPASDFGHJKLZXCVBNM--End of Line--

Transmitter 3 sends test sequence 1 through the water
This is a test sentence.--End of Line--

Transmitter 1 sends test sequence 5 and transmitter 3 sends test sequence 6 through the water
zzzzxxxxccccvvvvbbbbnmnmnm--End of Line--

Transmitter 1 sends test sequence 6 and transmitter 3 sends test sequence 5 through the water
aaaassssddddffffgggghjhjhj--End of Line--

Transmitter 1 sends test sequence 1 and transmitter 3 sends test sequence 7 through the water
qqqqqqqqqq--End of Line--

Transmitter 1 sends test sequence 7 and transmitter 3 sends test sequence 1 through the water
1234567890--End of Line--

FREQUENCY HOPPING CDMA AND FREQUENCY DIVISION LAKE TEST RESULTS

RECEIVED BY RBS-1 MODEM 2 (RECEIVER 2)

TEST DATA SEQUENCE 1 : 1234567890
TEST DATA SEQUENCE 2 : qwertyuiopasdfghjklzxcvbnm
TEST DATA SEQUENCE 3 : QWERTYUIOPASDFGHJKLZXCVBNM
TEST DATA SEQUENCE 4 : This is a test sentence.
TEST DATA SEQUENCE 5 : aaaassssddddffffgggghjhjhj
TEST DATA SEQUENCE 6 : zzzzxxxxccccvvvvbbbbnmnmnm
TEST DATA SEQUENCE 7 : qqqqqqqqqq

Transmitter 1 sends test sequence 1 through the water
--End of Line--

Transmitter 1 sends test sequence 2 through the water
--End of Line--

Transmitter 1 sends test sequence 3 through the water
--End of Line--

Transmitter 1 sends test sequence 4 through the water
--End of Line--

Transmitter 3 sends test sequence 1 through the water
ÿÿ1234567890--End of Line--

Transmitter 3 sends test sequence 2 through the water
qwertyuiopasdfghjklzxcvbnm--End of Line--

Transmitter 3 sends test sequence 3 through the water
QWERTYUIOPASDFGHJKLZXCVBNM--End of Line--

Transmitter 3 sends test sequence 4 through the water
This is a test sentence.--End of Line--

Transmitter 1 sends test sequence 5 and transmitter 3 sends test sequence 6 through the water
zzzzÿÿxxÿÿccvvvvbbbbÿÿÿÿÿÿ--End of Line--

Transmitter 1 sends test sequence 6 and transmitter 3 sends test sequence 5 through the water
aaaassssddÿÿÿÿÿÿgggghjhjÿÿ--End of Line--

Transmitter 1 sends test sequence 1 and transmitter 3 sends test sequence 7 through the water
qqÿÿqqqqqq--End of Line--

Transmitter 1 sends test sequence 7 and transmitter 3 sends test sequence 1 through the water
ÿÿ34567890--End of Line--

HYBRID (DS-TH) CDMA LAKE TEST RESULTS

RECEIVED BY RBS-1 MODEM 2 (RECEIVER 2)

TEST DATA SEQUENCE 1 : 1234567890
TEST DATA SEQUENCE 2 : qwertyuiopasdfghjklzxcvbnm
TEST DATA SEQUENCE 3 : QWERTYUIOPASDFGHJKLZXCVBNM
TEST DATA SEQUENCE 4 : This is a test sentence.
TEST DATA SEQUENCE 5 : aaaassssddddffffgggghjhjhj
TEST DATA SEQUENCE 6 : zzzzxxxxccccvvvvbbbbnmnmnm
TEST DATA SEQUENCE 7 : qqqqqqqqq

Transmitter 1 sends test sequence 1 through the water
ÿÿÿÿÿÿÿÿÿÿ--End of Line--

Transmitter 1 sends test sequence 1 through the water
ÿÿÿÿÿÿÿÿÿÿoÿÿoÿÿÿÿÿÿÿÿÿÿÿÿ--End of Line--

Transmitter 1 sends test sequence 1 through the water
ÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿ--End of Line--

Transmitter 1 sends test sequence 1 through the water
?ÿÿÿÿÿÿÿÿÿÿÿöÿÿöÿ~ÿÿÿoÿÿ--End of Line--

Transmitter 3 sends test sequence 1 through the water
1234567890--End of Line--

Transmitter 3 sends test sequence 2 through the water
qwertyuiopasdfghjklzxcvbnm--End of Line--

Transmitter 3 sends test sequence 3 through the water
QWERTYUIOPASDFGHJKLZXCVBNM--End of Line--

Transmitter 3 sends test sequence 4 through the water
This is a test sentence.--End of Line--

Transmitter 1 sends test sequence 5 and transmitter 3 sends test sequence 6 through the water
ÿÿÿðÿø?ÿÿoÿÿÿÿÿ&ÿÿÿÿÿÿöÿÿ--End of Line--

Transmitter 1 sends test sequence 6 and transmitter 3 sends test sequence 5 through the water
ÿÿÿÿÿoÿ□ÿÿÿÿÿÿÿÿoÿÿÿÿÿÿÿÿÿ--End of Line--

Transmitter 1 sends test sequence 1 and transmitter 3 sends test sequence 7 through the water
□ÿÿ¯ÿoÿÿÿ~--End of Line--

Transmitter 1 sends test sequence 7 and transmitter 3 sends test sequence 1 through the water
ÿÿÿÿÿÿ□ÿÿÿÿÿÿÿxÿÿÿÿÿ?ÿÿÿ--End of Line–

HYBRID (DS-TH) CDMA AND FREQUENCY DIVISION LAKE TEST RESULTS

RECEIVED BY RBS-1 MODEM 2 (RECEIVER 2)

TEST DATA SEQUENCE 1 : 1234567890
TEST DATA SEQUENCE 2 : qwertyuiopasdfghjklzxcvbnm
TEST DATA SEQUENCE 3 : QWERTYUIOPASDFGHJKLZXCVBNM
TEST DATA SEQUENCE 4 : This is a test sentence.
TEST DATA SEQUENCE 5 : aaaassssddddffffgggghjhjhj
TEST DATA SEQUENCE 6 : zzzzxxxxccccvvvvbbbbnmnmnm
TEST DATA SEQUENCE 7 : qqqqqqqqqq

Transmitter 1 sends test sequence 1 through the water
--End of Line--

Transmitter 1 sends test sequence 1 through the water
--End of Line--

Transmitter 1 sends test sequence 1 through the water
--End of Line--

Transmitter 1 sends test sequence 1 through the water
--End of Line--

Transmitter 3 sends test sequence 1 through the water
1234567890--End of Line--

Transmitter 3 sends test sequence 1 through the water
qwertyuiopasdfghjklzxcvbnm--End of Line--

Transmitter 3 sends test sequence 1 through the water
QWERTYUIOPASDFGHJKLZXCVBNM--End of Line--

Transmitter 3 sends test sequence 1 through the water
This is a test sentence.--End of Line--

Transmitter 1 sends test sequence 5 and transmitter 3 sends test sequence 6 through the water
zzúzxxxxcccc□□□f&&ö&æöæÖï--End of Line--

Transmitter 1 sends test sequence 6 and transmitter 3 sends test sequence 5 through the water
aaaassssddôdfföfövvö†¦†¦†§--End of Line--

Transmitter 1 sends test sequence 1 and transmitter 3 sends test sequence 7 through the water
□□□□□□□□□--End of Line--

Transmitter 1 sends test sequence 7 and transmitter 3 sends test sequence 1 through the water
/3C_csʃ“--End of Line--

FREQUENCY DIVISION LAKE TEST RESULTS

RECEIVED BY RBS-1 MODEM 4 (RECEIVER 4)

TEST DATA SEQUENCE 1 : 1234567890
TEST DATA SEQUENCE 2 : qwertyuiopasdfghjklzxcvbnm
TEST DATA SEQUENCE 3 : QWERTYUIOPASDFGHJKLZXCVBNM
TEST DATA SEQUENCE 4 : This is a test sentence.
TEST DATA SEQUENCE 5 : aaaassssddddffffgggghjhjhj
TEST DATA SEQUENCE 6 : zzzzxxxxccccvvvvbbbbnmnmnm
TEST DATA SEQUENCE 7 : qqqqqqqqqq

Transmitter 1 sends test sequence 1 through the water
1234567890--End of Line--

Transmitter 1 sends test sequence 2 through the water
qwertyuiopasdfghjklzxcvbnm--End of Line--

Transmitter 1 sends test sequence 3 through the water
QWERTYUIOPASDFGHJKLZXCVBNM--End of Line--

Transmitter 1 sends test sequence 4 through the water
This is a test sentence.--End of Line--

Transmitter 3 sends test sequence 1 through the water
--End of Line--

Transmitter 3 sends test sequence 2 through the water
--End of Line--

Transmitter 3 sends test sequence 3 through the water
--End of Line--

Transmitter 3 sends test sequence 4 through the water
--End of Line--

Transmitter 1 sends test sequence 5 and transmitter 3 sends test sequence 6 through the water
aaaassssddddffffgggghjhjhj--End of Line--

Transmitter 1 sends test sequence 6 and transmitter 3 sends test sequence 5 through the water
zzzzxxxxccccvvvvbbbbnmnmnm--End of Line--

Transmitter 1 sends test sequence 1 and transmitter 3 sends test sequence 7 through the water
1234567890--End of Line--

Transmitter 1 sends test sequence 7 and transmitter 3 sends test sequence 1 through the water
qqqqqqqqqq--End of Line--

```
DIRECT SEQUENCE CDMA LAKE TEST RESULTS

RECEIVED BY RBS-1 MODEM 4 (RECEIVER 4)

TEST DATA SEQUENCE 1 : 1234567890
TEST DATA SEQUENCE 2 : qwertyuiopasdfghjklzxcvbnm
TEST DATA SEQUENCE 3 : QWERTYUIOPASDFGHJKLZXCVBNM
TEST DATA SEQUENCE 4 : This is a test sentence.
TEST DATA SEQUENCE 5 : aaaassssddddffffgggghjhjhj
TEST DATA SEQUENCE 6 : zzzzxxxxccccvvvvbbbbnmnmnm
TEST DATA SEQUENCE 7 : qqqqqqqqqq

Transmitter 1 sends test sequence 1 through the water
1234567890--End of Line--

Transmitter 1 sends test sequence 2 through the water
qwertyuiopasdfghjklzxcvbnm--End of Line--

Transmitter 1 sends test sequence 3 through the water
QWERTYUIOPASDFGHJKLZXCVBNM--End of Line--

Transmitter 1 sends test sequence 4 through the water
This is a test sentence.--End of Line--

Transmitter 3 sends test sequence 1 through the water
          --End of Line--

Transmitter 3 sends test sequence 2 through the water
                          --End of Line--

Transmitter 3 sends test sequence 3 through the water
                          --End of Line--

Transmitter 3 sends test sequence 4 through the water
                       --End of Line--

Transmitter  1  sends  test  sequence  5  and  transmitter  3  sends  test
sequence 6 through the water
□□ □    □□□□□fff□□□□□¦†¦□ --End of Line--

Transmitter  1  sends  test  sequence  6  and  transmitter  3  sends  test
sequence 5 through the water
                               --End of Line--

Transmitter  1  sends  test  sequence  1  and  transmitter  3  sends  test
sequence 7 through the water
          --End of Line--

Transmitter  1  sends  test  sequence  7  and  transmitter  3  sends  test
sequence 1 through the water
   □      --End of Line--
```

```
DIRECT SEQUENCE CDMA LAKE TEST RESULTS (SPEED OPTION:2)

RECEIVED BY RBS-1 MODEM 4 (RECEIVER 4)

TEST DATA SEQUENCE 1 : 1234567890
TEST DATA SEQUENCE 2 : qwertyuiopasdfghjklzxcvbnm
TEST DATA SEQUENCE 3 : QWERTYUIOPASDFGHJKLZXCVBNM
TEST DATA SEQUENCE 4 : This is a test sentence.
TEST DATA SEQUENCE 5 : aaaassssddddffffgggghjhjhj
TEST DATA SEQUENCE 6 : zzzzxxxxccccvvvvbbbbnmnmnm
TEST DATA SEQUENCE 7 : qqqqqqqqqq

Transmitter 1 sends test sequence 1 through the water
          --End of Line--

Transmitter 1 sends test sequence 2 through the water
                          --End of Line--

Transmitter 1 sends test sequence 3 through the water
                          --End of Line--

Transmitter 1 sends test sequence 4 through the water
                        --End of Line--

Transmitter 3 sends test sequence 1 through the water
          --End of Line--

Transmitter 3 sends test sequence 2 through the water
                          --End of Line--

Transmitter 3 sends test sequence 3 through the water
                          --End of Line--

Transmitter 3 sends test sequence 4 through the water
                        --End of Line--

Transmitter  1  sends  test  sequence  5  and  transmitter  3  sends  test
sequence 6 through the water
                          --End of Line--

Transmitter  1  sends  test  sequence  6  and  transmitter  3  sends  test
sequence 5 through the water
                          --End of Line--

Transmitter  1  sends  test  sequence  1  and  transmitter  3  sends  test
sequence 7 through the water
          --End of Line--

Transmitter  1  sends  test  sequence  7  and  transmitter  3  sends  test
sequence 1 through the water
                  --End of Line--
```

DIRECT SEQUENCE CDMA AND FREQUENCY DIVISION LAKE TEST RESULTS

RECEIVED BY RBS-1 MODEM 4 (RECEIVER 4)

TEST DATA SEQUENCE 1 : 1234567890
TEST DATA SEQUENCE 2 : qwertyuiopasdfghjklzxcvbnm
TEST DATA SEQUENCE 3 : QWERTYUIOPASDFGHJKLZXCVBNM
TEST DATA SEQUENCE 4 : This is a test sentence.
TEST DATA SEQUENCE 5 : aaaassssddddffffgggghjhjhj
TEST DATA SEQUENCE 6 : zzzzxxxxccccvvvvbbbbnmnmnm
TEST DATA SEQUENCE 7 : qqqqqqqqqq

Transmitter 1 sends test sequence 1 through the water
1234567890--End of Line--

Transmitter 1 sends test sequence 2 through the water
qwertyuiopasdfghjklzxcvbnm--End of Line--

Transmitter 1 sends test sequence 3 through the water
QWERTYUIOPASDFGHJKLZXCVBNM--End of Line--

Transmitter 1 sends test sequence 4 through the water
This is a test sentence.--End of Line--

Transmitter 3 sends test sequence 1 through the water
--End of Line--

Transmitter 3 sends test sequence 2 through the water
--End of Line--

Transmitter 3 sends test sequence 3 through the water
--End of Line--

Transmitter 3 sends test sequence 4 through the water
--End of Line--

Transmitter 1 sends test sequence 5 and transmitter 3 sends test sequence 6 through the water
aaaassssddddffffgggghjhjhj--End of Line--

Transmitter 1 sends test sequence 6 and transmitter 3 sends test sequence 5 through the water
zzzzxxxxccccvvvvbbbbnmnmnm--End of Line--

Transmitter 1 sends test sequence 1 and transmitter 3 sends test sequence 7 through the water
1234567890--End of Line--

Transmitter 1 sends test sequence 7 and transmitter 3 sends test sequence 1 through the water
qqqqqqqqqq--End of Line--

TIME HOPPING CDMA LAKE TEST RESULTS

RECEIVED BY RBS-1 MODEM 4 (RECEIVER 4)

TEST DATA SEQUENCE 1 : 1234567890
TEST DATA SEQUENCE 2 : qwertyuiopasdfghjklzxcvbnm
TEST DATA SEQUENCE 3 : QWERTYUIOPASDFGHJKLZXCVBNM
TEST DATA SEQUENCE 4 : This is a test sentence.
TEST DATA SEQUENCE 5 : aaaassssddddffffgggghjhjhj
TEST DATA SEQUENCE 6 : zzzzxxxxccccvvvvbbbbnmnmnm
TEST DATA SEQUENCE 7 : qqqqqqqqqq

Transmitter 1 sends test sequence 1 through the water
1234567890--End of Line--

Transmitter 1 sends test sequence 2 through the water
qwertyuiopasdfghjklzxcvbnm--End of Line--

Transmitter 1 sends test sequence 3 through the water
QWERTYUIOPASDFGHJKLZXCVBNM--End of Line--

Transmitter 1 sends test sequence 4 through the water
This is a test sentence.--End of Line--

Transmitter 3 sends test sequence 1 through the water
ÿÿÿÿÿÿ--End of Line--

Transmitter 3 sends test sequence 2 through the water
ÿÿÿÿÿÿ--End of Line--

Transmitter 3 sends test sequence 3 through the water
ÿÿÿÿÿÿ--End of Line--

Transmitter 3 sends test sequence 4 through the water
ÿÿÿÿÿÿ--End of Line--

Transmitter 1 sends test sequence 5 and transmitter 3 sends test sequence 6 through the water
ÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿhjhj--End of Line--

Transmitter 1 sends test sequence 6 and transmitter 3 sends test sequence 5 through the water
□ÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿnmnmÿÿ --End of Line--

Transmitter 1 sends test sequence 1 and transmitter 3 sends test sequence 7 through the water
□ÿÿ90--End of Line--

Transmitter 1 sends test sequence 7 and transmitter 3 sends test sequence 1 through the water
ÿÿÿÿÿÿÿÿÿÿ--End of Line--

TIME HOPPING CDMA AND FREQUENCY DIVISION LAKE TEST RESULTS

RECEIVED BY RBS-1 MODEM 4 (RECEIVER 4)

TEST DATA SEQUENCE 1 : 1234567890
TEST DATA SEQUENCE 2 : qwertyuiopasdfghjklzxcvbnm
TEST DATA SEQUENCE 3 : QWERTYUIOPASDFGHJKLZXCVBNM
TEST DATA SEQUENCE 4 : This is a test sentence.
TEST DATA SEQUENCE 5 : aaaassssddddffffgggghjhjhj
TEST DATA SEQUENCE 6 : zzzzxxxxccccvvvvbbbbnmnmnm
TEST DATA SEQUENCE 7 : qqqqqqqqqq

Transmitter 1 sends test sequence 1 through the water
1234567890--End of Line--

Transmitter 1 sends test sequence 2 through the water
qwertyuiopasdfghjklzxcvbnm--End of Line--

Transmitter 1 sends test sequence 3 through the water
QWERTYUIOPASDFGHJKLZXCVBNM--End of Line--

Transmitter 1 sends test sequence 4 through the water
This is a test sentence.--End of Line--

Transmitter 3 sends test sequence 1 through the water
--End of Line--

Transmitter 3 sends test sequence 2 through the water
--End of Line--

Transmitter 3 sends test sequence 3 through the water
--End of Line--

Transmitter 3 sends test sequence 4 through the water
--End of Line--

Transmitter 1 sends test sequence 5 and transmitter 3 sends test sequence 6 through the water
aaÿÿssssÿÿddffffgggghjhjhj--End of Line--

Transmitter 1 sends test sequence 6 and transmitter 3 sends test sequence 5 through the water
zzzzxxxxccccvvvvbbbbÿÿnmnm--End of Line--

Transmitter 1 sends test sequence 1 and transmitter 3 sends test sequence 7 through the water
1234ÿÿ7890--End of Line--

Transmitter 1 sends test sequence 7 and transmitter 3 sends test sequence 1 through the water
qqÿÿqqqqqq--End of Line--

FREQUENCY HOPPING CDMA LAKE TEST RESULTS

RECEIVED BY RBS-1 MODEM 4 (RECEIVER 4)

TEST DATA SEQUENCE 1 : 1234567890
TEST DATA SEQUENCE 2 : qwertyuiopasdfghjklzxcvbnm
TEST DATA SEQUENCE 3 : QWERTYUIOPASDFGHJKLZXCVBNM
TEST DATA SEQUENCE 4 : This is a test sentence.
TEST DATA SEQUENCE 5 : aaaassssddddffffgggghjhjhj
TEST DATA SEQUENCE 6 : zzzzxxxxccccvvvvbbbbnmnmnm
TEST DATA SEQUENCE 7 : qqqqqqqqqq

Transmitter 1 sends test sequence 1 through the water
1234567890--End of Line--

Transmitter 1 sends test sequence 2 through the water
qwertyuiopasdfghjklzxcvbnm--End of Line--

Transmitter 1 sends test sequence 3 through the water
QWERTYUIOPASDFGHJKLZXCVBNM--End of Line--

Transmitter 1 sends test sequence 4 through the water
This is a test sentence.--End of Line--

Transmitter 3 sends test sequence 1 through the water
123456ÿÿ90--End of Line--

Transmitter 3 sends test sequence 1 through the water
qwerÿÿÿÿopasdfghjkÿÿxcvbnm--End of Line--

Transmitter 3 sends test sequence 1 through the water
ÿÿERÿÿÿÿOPASDFGHJKLZXCVBNM--End of Line--

Transmitter 3 sends test sequence 1 through the water
Thÿÿ is a test sentence.--End of Line--

Transmitter 1 sends test sequence 5 and transmitter 3 sends test sequence 6 through the water
aaaaÿÿÿÿddddffffgggghjhjhj--End of Line--

Transmitter 1 sends test sequence 6 and transmitter 3 sends test sequence 5 through the water
ÿÿaaÿÿÿÿÿÿddffÿÿÿÿÿÿÿÿhjhj--End of Line--

Transmitter 1 sends test sequence 1 and transmitter 3 sends test sequence 7 through the water
12ÿÿÿÿÿÿÿÿ--End of Line--

Transmitter 1 sends test sequence 7 and transmitter 3 sends test sequence 1 through the water
ÿÿÿÿqqÿÿÿÿ--End of Line--

FREQUENCY HOPPING CDMA LAKE TEST RESULTS (TRESHOLD:90)

RECEIVED BY RBS-1 MODEM 4 (RECEIVER 4)

TEST DATA SEQUENCE 1 : 1234567890
TEST DATA SEQUENCE 2 : qwertyuiopasdfghjklzxcvbnm
TEST DATA SEQUENCE 3 : QWERTYUIOPASDFGHJKLZXCVBNM
TEST DATA SEQUENCE 4 : This is a test sentence.
TEST DATA SEQUENCE 5 : aaaassssddddffffgggghjhjhj
TEST DATA SEQUENCE 6 : zzzzxxxxccccvvvvbbbbnmnmnm
TEST DATA SEQUENCE 7 : qqqqqqqqqq

Transmitter 1 sends test sequence 1 through the water
1234567890--End of Line--

Transmitter 1 sends test sequence 2 through the water
qwertyuiopasdfghjklzxcvbnm--End of Line--

Transmitter 1 sends test sequence 3 through the water
QWERTYUIOPASDFGHJKLZXCVBNM--End of Line--

Transmitter 1 sends test sequence 4 through the water
This is a test sentence.--End of Line--

Transmitter 3 sends test sequence 1 through the water
ÿÿÿÿ--End of Line--

Transmitter 3 sends test sequence 2 through the water
ÿÿÿÿÿÿÿÿÿÿÿÿ--End of Line--

Transmitter 3 sends test sequence 3 through the water
ÿÿÿÿÿÿÿÿÿÿÿÿ--End of Line--

Transmitter 3 sends test sequence 4 through the water
ÿÿÿÿÿÿÿÿÿÿÿÿ--End of Line--

Transmitter 1 sends test sequence 5 and transmitter 3 sends test sequence 6 through the water
aaaassssddddffffgggghjhjhj--End of Line--

Transmitter 1 sends test sequence 6 and transmitter 3 sends test sequence 5 through the water
zzzzxxÿÿÿÿÿÿvvvvbbbbnmnmÿÿ--End of Line--

Transmitter 1 sends test sequence 1 and transmitter 3 sends test sequence 7 through the water
1234567890--End of Line--

Transmitter 1 sends test sequence 7 and transmitter 3 sends test sequence 1 through the water
qqqqqqqqqq--End of Line--

FREQUENCY HOPPING CDMA AND FREQUENCY DIVISION LAKE TEST RESULTS

RECEIVED BY RBS-1 MODEM 4 (RECEIVER 4)

TEST DATA SEQUENCE 1 : 1234567890
TEST DATA SEQUENCE 2 : qwertyuiopasdfghjklzxcvbnm
TEST DATA SEQUENCE 3 : QWERTYUIOPASDFGHJKLZXCVBNM
TEST DATA SEQUENCE 4 : This is a test sentence.
TEST DATA SEQUENCE 5 : aaaassssddddffffgggghjhjhj
TEST DATA SEQUENCE 6 : zzzzxxxxccccvvvvbbbbnmnmnm
TEST DATA SEQUENCE 7 : qqqqqqqqqq

Transmitter 1 sends test sequence 1 through the water
1234567890--End of Line--

Transmitter 1 sends test sequence 2 through the water
qwertyuiopasdfghjklzxcvbnm--End of Line--

Transmitter 1 sends test sequence 3 through the water
QWERTYUIOPASDFGHJKLZXCVBNM--End of Line--

Transmitter 1 sends test sequence 4 through the water
This is a test sentence.--End of Line--

Transmitter 3 sends test sequence 1 through the water
--End of Line--

Transmitter 3 sends test sequence 2 through the water
--End of Line--

Transmitter 3 sends test sequence 3 through the water
--End of Line--

Transmitter 3 sends test sequence 4 through the water
--End of Line--

Transmitter 1 sends test sequence 5 and transmitter 3 sends test sequence 6 through the water
aaaassssddddffffÿÿÿÿhjhjhj--End of Line--

Transmitter 1 sends test sequence 6 and transmitter 3 sends test sequence 5 through the water
ÿÿÿÿxxxxccccvvvvbbbbnmnmnm--End of Line--

Transmitter 1 sends test sequence 1 and transmitter 3 sends test sequence 7 through the water
1234ÿÿÿÿ90--End of Line--

Transmitter 1 sends test sequence 7 and transmitter 3 sends test sequence 1 through the water
qqqqqqqqqq--End of Line--

```
HYBRID (DS-TH) CDMA LAKE TEST RESULTS

RECEIVED BY RBS-1 MODEM 4 (RECEIVER 4)

TEST DATA SEQUENCE 1 : 1234567890
TEST DATA SEQUENCE 2 : qwertyuiopasdfghjklzxcvbnm
TEST DATA SEQUENCE 3 : QWERTYUIOPASDFGHJKLZXCVBNM
TEST DATA SEQUENCE 4 : This is a test sentence.
TEST DATA SEQUENCE 5 : aaaassssddddffffgggghjhjhj
TEST DATA SEQUENCE 6 : zzzzxxxxccccvvvvbbbbnmnmnm
TEST DATA SEQUENCE 7 : qqqqqqqqqq

Transmitter 1 sends test sequence 1 through the water
1234567890--End of Line--

Transmitter 1 sends test sequence 2 through the water
qwertyui□pasdfghjklzxcvbnm--End of Line--

Transmitter 1 sends test sequence 3 through the water
QWERTYUIOPASDFGHJKLZXCVBNM--End of Line--

Transmitter 1 sends test sequence 4 through the water
This is a test sentence.--End of Line--

Transmitter 3 sends test sequence 1 through the water
          --End of Line--

Transmitter 3 sends test sequence 2 through the water
                          --End of Line--

Transmitter 3 sends test sequence 3 through the water
                          --End of Line--

Transmitter 3 sends test sequence 4 through the water
  --End of Line--

Transmitter 1 sends test sequence 5 and transmitter 3 sends test
sequence 6 through the water
jh--End of Line--

Transmitter 1 sends test sequence 6 and transmitter 3 sends test
sequence 5 through the water
                   mnmn--End of Line--

Transmitter 1 sends test sequence 1 and transmitter 3 sends test
sequence 7 through the water
  □    □9--End of Line--

Transmitter 1 sends test sequence 7 and transmitter 3 sends test
sequence 1 through the water
        q--End of Line--
```

HYBRID (DS-TH) CDMA AND FREQUENCY DIVISION LAKE TEST RESULTS

RECEIVED BY RBS-1 MODEM 4 (RECEIVER 4)

TEST DATA SEQUENCE 1 : 1234567890
TEST DATA SEQUENCE 2 : qwertyuiopasdfghjklzxcvbnm
TEST DATA SEQUENCE 3 : QWERTYUIOPASDFGHJKLZXCVBNM
TEST DATA SEQUENCE 4 : This is a test sentence.
TEST DATA SEQUENCE 5 : aaaassssddddffffgggghjhjhj
TEST DATA SEQUENCE 6 : zzzzxxxxccccvvvvbbbbnmnmnm
TEST DATA SEQUENCE 7 : qqqqqqqqqq

Transmitter 1 sends test sequence 1 through the water
1234567890--End of Line--

Transmitter 1 sends test sequence 2 through the water
qwertyuiopasdfghjklzxcvbnm--End of Line--

Transmitter 1 sends test sequence 3 through the water
QWERTYUIOPASDFGHJKLZXCVBNM--End of Line--

Transmitter 1 sends test sequence 4 through the water
This is a test sentence.--End of Line--

Transmitter 3 sends test sequence 1 through the water
--End of Line--

Transmitter 3 sends test sequence 2 through the water
--End of Line--

Transmitter 3 sends test sequence 3 through the water
--End of Line--

Transmitter 3 sends test sequence 4 through the water
--End of Line--

Transmitter 1 sends test sequence 5 and transmitter 3 sends test sequence 6 through the water
a□aasss□dddffffg□g□jhjhj--End of Line--

Transmitter 1 sends test sequence 6 and transmitter 3 sends test sequence 5 through the water
zzzxxxccccvvvbb□bnmnmnm--End of Line--

Transmitter 1 sends test sequence 1 and transmitter 3 sends test sequence 7 through the water
□2□45□7890--End of Line--

Transmitter 1 sends test sequence 7 and transmitter 3 sends test sequence 1 through the water
qq□qqqqq--End of Line--

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